SUBAREA 1.0 BASIC PRINCIPLES OF SCIENCE (HISTORY AND NATURAL SCIENCE)

Competency 1.1 Nature of scientific knowledge, inquiry, and historical perspectives:

Skill 1.1.1 Scientific methods

Scientific research serves two purposes –

1. To investigate and acquire knowledge that is theoretical *and*
2. To do research which is of practical value

Science is in a unique position to be able to serve humanity. Scientific research comes from inquiry. An inquiring mind is thirsty, trying to find answers. A person who is inquisitive asks questions and wants to find out answers. The two most important questions – why and how – are the starting points of all inquiry.

Scientific research uses the scientific method to answer questions. Researchers follow the scientific method, which consists of a series of steps designed to solve a problem.

The aim of the scientific method is to eliminate any bias or prejudice that the scientist or researcher may bring to the inquiry. If we follow all the steps of the scientific method as outlined, we achieve maximum elimination of bias.

The scientific method consists of the following steps –

1. Stating the problem clearly and precisely
2. Gathering information/research
3. Formulating a hypothesis (an educated guess)
4. Designing an experiment
5. Analyzing the results
6. Drawing a conclusion

Skill 1.1.2 Processes involved in scientific inquiry

Science is a body of knowledge systematically derived from study, observations, and experimentation. Its goal is to identify and establish principles and theories that may be applied to solve problems. Pseudoscience, on the other hand, involves beliefs that are not supported by hard evidence. In other words, there is no scientific methodology or application. Some classic examples of pseudoscience include witchcraft, alien encounters, or any topic explained by hearsay.

Scientific experimentation must be repeatable. Experimentation results in theories that can be disproved and changed. Science depends on communication, agreement, and disagreement among scientists. It is composed of theories, laws, and hypotheses.

Skill 1.1.3 Process skills

Theory - A statement of principles or relationships relating to a natural event or phenomenon, which has been verified and accepted.

Law - An explanation of events that occur with uniformity under the same conditions (e.g., laws of nature, law of gravitation).

Hypothesis - An unproved theory or educated guess followed by research to best explain a phenomenon. A theory is a proven hypothesis.

Science is limited by the available technology. An example of this would be the relationship between the discovery of the cell and the invention of the microscope. As our technology improves, more hypotheses will become theories and possibly laws. Data collection methods also limit scientific inquiry. Data may be interpreted differently on different occasions. Limitations of scientific methodology produce explanations that change as new technologies emerge.

Skill 1.1.4 Facts

Facts are not always as finite as they appear. More commonly in science, information is a hypothesis or, once tested and confirmed, a theory. Theories exist for long periods of time and repeatedly receive challenges. Only when a theory has withstood every challenge and been proven to provide reproducible results does it become recognized as a law. It is the universal recognition that defines a theory as a scientific law.

Skill 1.1.5 Concepts

A concept is a general understanding or belief. Scientists challenge concepts. The purpose of the scientific method is to derive clear, unbiased data. Concepts, on the other hand, may be fraught with personal biases and gray areas, overly simplistic, or too encompassing. A scientist might examine a concept, and then try to confirm it by making and testing a hypothesis. In this way, scientific inquiry is more specific and concepts are more generalized.

Skill 1.1.6 Models

Models are the basis for greater understanding. Models are usually small-scale representations that help us understand a larger system. Models aid us by making unusually large or small items more concrete. Common models include the solar system and the DNA helix. It is important to note that models are created with information. How current and accurate the information is at the time of creation may make the model more or less useful at a later time. For example, at the time of this publication, Pluto's place as a planet is being challenged, although it has been widely accepted for many years.

It is possible that today's models may become obsolete following the resolution of Pluto's status. This is due to the progressive nature of science; the more we learn, the more we are forced to reevaluate.

Skill 1.1.7 Commonly shared scientific ideals

Biological science is closely connected to technology and the other sciences and greatly impacts society and everyday life. Scientific discoveries often lead to technological advances. Conversely, technology is often necessary for scientific investigation and advances in technology often expand the reach of scientific discoveries. In addition, biology and the other scientific disciplines share several unifying concepts and processes that help unify the study of science. Finally, because biology is the science of living systems, biology directly impacts society and everyday life.

Science and technology, while distinct concepts, are closely related. Science attempts to investigate and explain the natural world, while technology attempts to solve human adaptation problems. Technology often results from the application of scientific discoveries, and advances in technology can increase the impact of scientific discoveries. For example, Watson and Crick used science to discover the structure of DNA and their discovery led to many biotechnological advances in the manipulation of DNA. These technological advances greatly influenced the medical and pharmaceutical fields. The success of Watson and Crick's experiments, however, was dependent on the technology available. Without the necessary technology, the experiments would have failed.

The combination of biology and technology has improved the human standard of living in many ways. However, the negative impact of increasing human life expectancy and population on the environment is problematic. In addition, advances in biotechnology (e.g. genetic engineering, cloning) produce ethical dilemmas that society must consider.

The following are the concepts and processes generally recognized as common to all scientific disciplines:

- Systems, order, and organization
- Evidence, models, and explanation
- Constancy, change, and measurement
- Evolution and equilibrium
- Form and function

Because the natural world is so complex, the study of science involves the **organization** of items into smaller groups based on interaction or interdependence. These groups are called **systems**. Examples of organization are the periodic table of elements and the five-kingdom classification scheme for living organisms.

Examples of systems are the solar system, cardiovascular system, Newton's laws of force and motion, and the laws of conservation.

Order refers to the behavior and measurability of organisms and events in nature. The arrangement of planets in the solar system and the life cycle of bacterial cells are examples of order.

Scientists use **evidence** and **models** to form **explanations** of natural events. Models are miniaturized representations of a larger event or system. Evidence is anything that furnishes proof.

Constancy and **change** describe the observable properties of natural organisms and events. Scientists use different systems of **measurement** to observe change and constancy. For example, the freezing and melting points of given substances and the speed of sound are constant under constant conditions. Growth, decay, and erosion are all examples of natural change.

Evolution is the process of change over a long period of time. While biological evolution is the most common example, one can also classify technological advancement, changes in the universe, and changes in the environment as evolution.

Equilibrium is the state of balance between opposing forces of change. Homeostasis and ecological balance are examples of equilibrium.

Form and **function** are properties of organisms and systems that are closely related. The function of an object usually dictates its form and the form of an object usually facilitates its function. For example, the form of the heart (e.g. muscle, valves) allows it to perform its function of circulating blood through the body.

Skill 1.1.8 Philosophy

To understand scientific ethics, we need to have a clear understanding of general ethics. Ethics is a system of public, general rules for guiding human conduct (Gert, 1988). The rules are general because they apply to all people at all times and they are public because they are not secret codes or practices.

Philosophers have given a number of moral theories to justify moral rules, which range from utilitarianism (a theory of ethics that prescribes the quantitative maximization of good consequences for a population proposed by Mozi, a Chinese philosopher who lived from 471-381 BC,) Kantianism (a theory proposed by Immanuel Kant, a German philosopher who lived from 1724-1804, which ascribes intrinsic value to rational beings and is the philosophical foundation of contemporary human rights) to social contract theory (a view of the ancient Greeks which states that the person's moral and or political obligations are dependent upon a contract or agreement between them to form society).

The following are some of the guiding principles of scientific ethics:

1. Scientific Honesty: refrain from fabricating or misinterpreting data for personal gain
2. Caution: avoid errors and sloppiness in all scientific experimentation
3. Credit: give credit where credit is due and do not copy
4. Responsibility: report reliable information to the public and do not mislead in the name of science
5. Freedom: freedom to criticize old ideas, question new research, and conduct independent research.

Scientists should show good conduct in their scientific pursuits. Conduct here refers to all aspects of scientific activity including experimentation, testing, education, data evaluation, data analysis, data storing, and peer review.

Skill 1.1.9 Contributions made by major historical figures and landmark events in the field of biology

Anton van Leeuwenhoek is known as the father of microscopy. In the 1650s, Leeuwenhoek began making tiny lenses that produced magnifications up to 300x. He was the first to see and describe bacteria, yeast plants, and the microscopic life found in water. Over the years, light microscopes have advanced to produce greater clarity and magnification. The scanning electron microscope (SEM) was developed in the 1950s. Instead of light, a beam of electrons passes through the specimen. Scanning electron microscopes have a resolution about one thousand times greater than light microscopes. The disadvantage of the SEM is that the chemical and physical methods used to prepare the sample result in the death of the specimen.

In the late 1800s, Pasteur discovered the role of microorganisms in the cause of disease, pasteurization, and the rabies vaccine. Koch took this observation one step further by formulating a theory that specific pathogens caused specific diseases. Scientists still use **Koch's postulates** as guidelines in the field of microbiology. The guidelines state that the same pathogen must be found in every diseased person, the pathogen must be isolated and grown in culture, the pathogen must induce disease in experimental animals, and the same pathogen must be isolated from the experimental animal.

The discovery of the structure of DNA was another key event in biological study. In the 1950s, James Watson and Francis Crick identified the structure of a DNA molecule as that of a double helix. This structure made it possible to explain DNA's ability to replicate and to control the synthesis of proteins.

The use of animals in biological research has expedited many scientific discoveries. Animal research has allowed scientists to learn more about animal biological systems, including the circulatory and reproductive systems. One significant use of animals is for the testing of drugs, vaccines, and other products (such as perfumes and shampoos) before use or consumption by humans.

Competency 1.2 Mathematics, measurement, and data manipulation

Math, science, and technology share many common themes. All three use models, diagrams, and graphs to simplify a concept for analysis and interpretation. Patterns observed in these systems lead to predictions based on these observations. Another common theme among these three systems is equilibrium. **Equilibrium** is a state in which forces are balanced, resulting in stability. Static equilibrium is stability due to a lack of changes, and dynamic equilibrium is stability due to a balance between opposing forces.

Skill 1.2.1 Measurement and notation systems

Science uses the **metric system**, as it is accepted worldwide and allows easier comparison among experiments done by scientists around the world.

The meter is the basic metric unit of length. One meter is 1.1 yards. The liter is the basic metric unit of volume. 3.846 liters is 1 gallon. The gram is the basic metric unit of mass. 1000 grams is 2.2 pounds.

The following prefixes define multiples of the basic metric units.

deca- 10X the base unit	deci - 1/10 the base unit
hecto- 100X the base unit	centi - 1/100 the base unit
kilo- 1,000X the base unit	milli - 1/1,000 the base unit
mega- 1,000,000X the base unit	micro- 1/1,000,000 the base unit
giga- 1,000,000,000X the base unit	nano- 1/1,000,000,000 the base unit
tera- 1,000,000,000,000X the base unit	pico- 1/1,000,000,000,000 the base unit

The common instrument used for measuring volume is the graduated cylinder. The standard unit of measurement is milliliters (mL). To ensure accurate measurement, it is important to read the liquid in the cylinder at the bottom of the meniscus, the curved surface of the liquid.

The common instrument used in measuring mass is the triple beam balance. The triple beam balance can accurately measure tenths of a gram and can estimate hundredths of a gram.

The ruler and meter stick are the most commonly used instruments for measuring length. As with all scientific measurements, standard units of length are metric.

Skill 1.2.2 Data collection

The procedure used to obtain data is important to the outcome. Experiments consist of **controls** and **variables**. A control is the experiment run under normal, unmanipulated conditions.

A variable is a factor or condition the scientist manipulates. In biology, the variable may be light, temperature, pH, time, etc. Scientists can use the differences in tested variables to make predictions or form hypotheses. Only one variable should be tested at a time. In other words, one would not alter both the temperature and pH of the experimental subject.

An **independent variable** is one the researcher directly changes or manipulates. This could be the amount of light given to a plant or the temperature at which bacteria is grown. The **dependent variable** is the factor that changes due to the influence of the independent variable.

Skill 1.2.3 Data manipulation

Data manipulation is important to experimental study. Data manipulation begins by altering one variable at a time, and then assessing the results. Are the results similar to the last time? What has changed? Has it improved or worsened? This process is part of the scientific method, where scientists make predictions and then experiment to test validity. Quite often, this process takes many alterations, and manipulating the data and experimental parameters is useful. We are fortunate to have technological advances to aid us in this area. Biologists use a variety of tools and technologies to perform tests, collect and display data, and analyze relationships. Examples of commonly used tools include computer-linked probes, spreadsheets, and graphing calculators.

Biologists use computer-linked probes to measure various environmental factors including temperature, dissolved oxygen, pH, ionic concentration, and pressure. The advantage of computer-linked probes, as compared to more traditional observational tools, is that the probes automatically gather data and present it in an accessible format. This property of computer-linked probes eliminates the need for constant human observation and manipulation.

Biologists use spreadsheets to organize, analyze, and display data. For example, conservation ecologists use spreadsheets to model population growth and development, apply sampling techniques, and create statistical distributions to analyze relationships. Spreadsheet use simplifies data collection and manipulation and allows the presentation of data in a logical and understandable format.

Graphing calculators are another technology with many applications to biology. For example, biologists use algebraic functions to analyze growth, development and other natural processes.

Graphing calculators can manipulate algebraic data and create graphs for analysis and observation. In addition, biologists use the matrix function of graphing calculators to model problems in genetics. The use of graphing calculators simplifies the creation of graphical displays including histograms, scatter plots, and line graphs. Biologists can also transfer data and displays to computers for further analysis. Finally, biologists connect computer-linked probes, used to collect data, to graphing calculators to ease the collection, transmission, and analysis of data.

While it is useful to manipulate data in discovery efforts, it is never acceptable to fabricate or falsely advertise your data.

Skill 1.2.4 Data interpretation

When interpreting data, one must carefully examine all parameters. Two of the most important aspects of science are data and honesty. You may be attempting to interpret your own data, or to understand data you found in a published format. Either way, it is important to think about what you see. In the scientific realm, numbers are stronger than words, so be sure to provide accurate data and examples to support your comments. By using the scientific method, you will be more likely to catch mistakes, correct biases, and obtain accurate results. When assessing experimental data, utilize proper tools and mathematical concepts. Because people often attempt to use scientific evidence in support of political or personal agendas, the ability to evaluate the credibility of scientific claims is a necessary skill in today's society. In evaluating scientific claims made in the media, public debates, and advertising, one should follow several guidelines.

First, scientific, peer-reviewed journals are the most accepted source for information on scientific experiments and studies. One should carefully scrutinize any claim that does not reference peer-reviewed literature.

Second, the media and those with an agenda to advance (e.g., advertisers and debaters) often overemphasize the certainty and importance of experimental results. One should question any scientific claim that sounds either too good to be true or overly certain.

Finally, knowledge of experimental design and the scientific method is important in evaluating the credibility of studies. For example, one should look for the inclusion of control groups and the presence of data to support the given conclusions.

Skill 1.2.5 Data presentation (tables, graphs, charts, error analysis)

The type of graphic representation used to display observations depends on the type of data collected. **Line graphs** compare different sets of related data and help predict data. For example, a line graph could compare the rate of activity of different enzymes at varying temperatures. A **bar graph** or **histogram** compares different items and helps make comparisons based on the data. For example, a bar graph could compare the ages of children in a classroom. A **pie chart** is useful when organizing data as part of a whole. For example, a pie chart could display the percent of time students spend on various after school activities.

As previously noted, the researcher controls the independent variable. The independent variable is placed on the x-axis (horizontal axis). The dependent variable is influenced by the independent variable and is placed on the y-axis (vertical axis). It is important to choose the appropriate units for labeling the axes. It is best to divide the largest value to be plotted by the number of blocks on the graph, and round to the nearest whole number.