

**DOMAIN 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 perform research which is of practical value

Science has the unique ability to serve humanity. Scientific research results from inquiry. An inquiring mind is thirsty, trying to find answers. An inquisitive person asks questions and wants to find answers. The two most important questions – why and how – are the starting points of all scientific 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

**Sample Test Question and Rationale**

1. **Identify the control in the following experiment. A student grew four plants under the following conditions and measured photosynthetic rate by measuring mass. He grew two plants in 50% light and two plants in 100% light.**  
*(Average Rigor)*

- A. plants grown with no added nutrients.
- B. plants grown in the dark.
- C. plants grown in 100% light.
- D. plants grown in 50% light.

**Answer: C. plants grown in 100% light.**

The plants grown in 100% light are the control that the student will compare the plants grown in 50% light.

**Skill 1.1.2 Processes involved in scientific inquiry**

Science is a body of knowledge systematically derived from study, observations, and experimentation. The objective of science is to identify and establish principles and theories that are utilized 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.

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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. The inherent limitations of scientific methodology produce results or explanations that are subject to 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 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.

### **Sample Test Question and Rationale**

2. **The concept that the rate of a given process is controlled by the most scarce factor in the process is known as?**  
*(Average Rigor)*
- A. The Rate of Origination.
  - B. The Law of the Minimum.
  - C. The Law of Limitation.
  - D. The Law of Conservation.

**Answer: B. The Law of the Minimum**

A limiting factor is the component of a biological process that determines how quickly or slowly the process proceeds. Photosynthesis is the main biological process determining the rate of ecosystem productivity or the rate at which an ecosystem creates biomass. Thus, in evaluating the productivity of an ecosystem, potential limiting factors are light intensity, gas concentrations, and mineral availability. The Law of the Minimum states that the required factor which is most scarce in a given process controls the rate of the process.

### **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 later. For example, although Pluto has been considered a planet for many years, it is now considered a dwarf planet. 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 other scientific disciplines and technology resulting in a tremendous impact on 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 concepts and processes that help unify the study of science. Finally, because biology is the science of living systems, biology directly affects 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 field of genomics. 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.

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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 point of a given substance 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 that guide human conduct. 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 provided a number of moral theories to justify moral rules ranging from utilitarianism to social contract theory. Utilitarianism, proposed by Mozi, a Chinese philosopher who lived from 471-381 BC, is a theory of ethics based on the determination of what is best for the greatest number of people. Kantianism, a theory proposed by Immanuel Kant, a German philosopher who lived from 1724-1804, ascribes intrinsic value to rational beings. Kantianism is the philosophical foundation of contemporary human rights. Social contract theory, on the other hand, is a view of the ancient Greeks, which states that a person's moral and/or political obligations are dependent upon a contract or societal agreement.

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 300 times. 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 pass 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.

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In the late 1800s, Pasteur invented pasteurization, the first rabies vaccine, and performed experiments that supported the germ theory of disease. Koch took this observation one-step further by formulating a theory that specific pathogens cause 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 history. 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.

### Sample Test Question and Rationale

3. Which of the following discovered penicillin?  
(*Rigorous*)
- A. Pierre Curie
  - B. Becquerel
  - C. Louis Pasteur
  - D. Alexander Fleming

**Answer: D. Alexander Fleming**

Sir Alexander Fleming was a pharmacologist from Scotland. He isolated the antibiotic penicillin from a fungus in 1928.

### 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.

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### Skill 1.2.1 Measurement and notation systems

Science uses the **metric system**, as it is accepted worldwide and allows the results of experiments, performed by different scientists around the world, to be compared to one another. 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. One thousand grams is 2.2 pounds. The following prefixes define multiples of the basic metric units.

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

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.

### Sample Test Question and Rationale

4. The International System of Units (SI) measurement for temperature is on the \_\_\_\_\_ scale.  
(Rigorous)
- A. Celsius
  - B. Fahrenheit
  - C. Kelvin
  - D. Rankine

**Answer: C. Kelvin**

Science uses the SI system because of its worldwide acceptance and ease of comparison. The SI scale for measuring temperature is the Kelvin Scale. Science, however, uses the Celsius scale for its ease of use. The answer is (C).

### 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, non-manipulated 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 programs are another technology with many applications to biology. For example, biologists use algebraic functions to analyze growth, development and other natural processes. Graphing programs can manipulate algebraic data and create graphs for analysis and observation. In addition, biologists use the matrix function of graphing programs to model problems in genetics. The use of graphing programs simplifies the creation of graphical displays including histograms, scatter plots, and line graphs. Finally, biologists connect computer-linked probes, used to collect data, to graphing programs 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.

### Sample Test Questions and Rationale

5. In a data set, the value that occurs with the greatest frequency is referred to as the...  
*(Average Rigor)*
- A. Mean
  - B. Median
  - C. Mode
  - D. Range

**Answer: C. Mode**

Mean is the mathematical average of all the items. The median depends on whether the number of items is odd or even. If the number is odd, then the median is the value of the item in the middle. Mode is the value of the item that occurs the most often, if there are not many items. Bimodal is a situation where there are two items with equal frequency. Range is the difference between the maximum and minimum values.

6. Three plants were grown and the following data recorded. Determine the mean growth.  
(Easy)

Plant 1: 10 cm

Plant 2: 20 cm

Plant 3: 15 cm

- A. 5 cm
- B. 45 cm
- C. 12 cm
- D. 15 cm

**Answer: D. 15 cm**

The mean growth is the average of the three growth heights.

$$\frac{10 + 20 + 15}{3} = 15 \text{ cm average height}$$

#### **Skill 1.2.4 Data interpretation**

When interpreting data, one must carefully examine all parameters. 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.

### **Sample Test Question and Rationale**

7. **In which of the following situations would a linear extrapolation of data be appropriate?**  
*(Rigorous)*

- A. Computing the death rate of an emerging disease
- B. Computing the number of plant species in a forest over time
- C. Computing the rate of diffusion with a constant gradient
- D. Computing the population at equilibrium

**Answer: C: Computing the rate of diffusion with a constant gradient.**

The individual data points on a linear graph cluster around a line of best fit. In other words, a relationship is linear if we can sketch a straight line that roughly fits the data points. Extrapolation is the process of estimating data points outside a known set of data points. When extrapolating data of a linear relationship, we extend the line of best fit beyond the known values. The extension of the line represents the estimated data points. Extrapolating data is only appropriate if we are relatively certain that the relationship is indeed linear. The answer is (C).

### Competency 1.3 Laboratory procedures and safety

#### Skill 1.3.1 Safe preparation, storage, use, and disposal of laboratory and field materials

All laboratory solutions should be prepared as directed in the lab manual. Care should be taken to avoid contamination. All glassware should be rinsed thoroughly with distilled water before using and cleaned well after use. All solutions should be made with distilled water as tap water contains dissolved particles that may affect the results of an experiment. Unused solutions should be disposed of according to local disposal procedures.

The "Right to Know Law" covers science teachers who work with potentially hazardous chemicals. Briefly, the law states that employees must be informed of potentially toxic chemicals. An inventory must be made available if requested. The inventory must contain information about the hazards and properties of the chemicals. This inventory is to be checked against the "Substance List". Training must be provided on safe handling and interpretation of the Material Safety Data Sheet.

The following chemicals are potential carcinogens and not allowed in school facilities: Acrylonitrile, Arsenic compounds, Asbestos, Benzidine, Benzene, Cadmium compounds, Chloroform, Chromium compounds, Ethylene oxide, Ortho-toluidine, Nickel powder, and Mercury.

Chemicals should not be stored on bench tops or heat sources. They should be stored in groups based on their reactivity with one another and in protective storage cabinets. All containers within the lab must be labeled. Suspected and known carcinogens must be labeled as such and stored in trays to contain leaks and spills.

Chemical waste should be disposed of in properly labeled containers. Waste should be separated based on its reactivity with other chemicals.

Biological material should never be stored near food or water used for human consumption. All biological material should be appropriately labeled. All blood and body fluids should be put in a well-contained container with a secure lid to prevent leaking. All biological waste should be disposed of in biological hazardous waste bags.

Material safety data sheets are available for every chemical and biological substance. These are available directly from the distribution company and the internet. Before using lab equipment, all lab workers should read and understand the equipment manuals.

**Sample Test Question and Rationale**

8. Which of the following is not usually found on the MSDS for a laboratory chemical?  
(Rigorous)

- A. Melting Point
- B. Toxicity
- C. Storage Instructions
- D. Cost

**Answer: D. Cost**

MSDS, or Material Safety Data Sheets, are used to make sure that anyone can easily obtain information about a chemical especially in the event of a spill or accident. This information typically includes physical data, toxicity, health effects, first aid, reactivity, storage, disposal, protective measures, and spill/leak procedures. Cost is not generally included on MSDS's. Costs are generated by the distributor, and separate suppliers may have different costs. The answer, therefore, is (D).

**Skill 1.3.2 Selection and use of appropriate laboratory equipment**

Light microscopes are commonly used in high school laboratory experiments. Total magnification is determined by multiplying the magnification of the ocular and objective lenses. Oculars usually magnify 10X and objective lenses usually magnify 10X on low and 40X on high.

Procedures for the care and use of microscopes include:

- cleaning all lenses with lens paper only,
- carrying microscopes with two hands (one on the arm and one on the base),
- always beginning on low power when focusing before switching to high power,
- storing microscopes with the low power objective down,
- always using a coverslip when viewing wet mount slides, *and*
- bringing the objective down to its lowest position then focusing, moving up to avoid breaking the slide or scratching the lens.

**Wet mount slides** should be made by placing a drop of water on the specimen and then putting a glass coverslip on top of the drop of water. Dropping the coverslip at a forty-five degree angle will help avoid air bubbles.

**Chromatography** refers to a set of techniques that are used to separate substances based on their different properties such as size or charge. Paper chromatography uses the principles of capillarity to separate substances such as plant pigments. Molecules of a larger size will move more slowly up the paper, whereas smaller molecules will move more quickly producing lines of pigment.

An **indicator** is any substance used to assist in the classification of another substance. An example of an indicator is litmus paper. Litmus paper is a way to measure whether a substance is acidic or basic. Blue litmus turns pink when acid is placed on it and pink litmus turns blue when a base is placed on it. pH paper is a more accurate measure of pH, with the paper turning different colors depending on the pH value.

**Spectrophotometers** measure the percent of light at different wavelengths absorbed and transmitted by a pigment solution.

**Centrifugation** involves spinning substances at a high speed. The more dense part of a solution will settle to the bottom of the test tube, where the lighter material will stay on top. Centrifugation is used to separate blood into blood cells and plasma, with the heavier blood cells settling to the bottom.

**Electrophoresis** uses electrical charges of molecules to separate them according to their size. The molecules, such as DNA or proteins are pulled through a gel towards either the positive end of the gel box (if the material has a negative charge) or the negative end of the gel box (if the material has a positive charge). DNA is negatively charged and moves towards the positive charge. Smaller segments of DNA will move more quickly toward the positive charge than larger segments.

### Sample Test Question and Rationale

9. **Paper chromatography is most often associated with the separation of...**  
*(Average Rigor)*

- A. nutritional elements.
- B. DNA.
- C. proteins.
- D. plant pigments.

**Answer: D. plant pigments.**

Paper chromatography uses the principles of capillarity to separate substances such as plant pigments. Molecules of a larger size will move more slowly up the paper, whereas smaller molecules will move more quickly producing lines of pigment.