Subarea I. Scientific Inquiry

0001 Apply procedures for gathering, organizing, interpreting, evaluating, and communicating data

Methods or procedures for collecting data

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 is 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.

Appropriate measuring devices

The most 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 most common instrument used for 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.

The metric system

The **metric system** is the most accepted system of scientific measurement worldwide. Scientists use the metric system because it allows easier comparison of experimental results produced 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

Knowledge of appropriate and effective graphic representation of data

The type of graphic representation used to present results 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.

Knowledge of labeling graphs with independent and dependent variables

The independent variable is placed on the x-axis (horizontal axis) and the dependent variable 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.

0002 Apply principles and procedures of research and experimental design

The Scientific Method

The first step in scientific inquiry is posing a question. Next, a hypothesis is formed to provide a plausible explanation. An experiment is then proposed and performed to test this hypothesis. A comparison between the predicted and observed results is the next step. Conclusions are then formed and it is determined whether the hypothesis is correct or incorrect. If incorrect, the next step is to form a new hypothesis and repeat the process.

Ask a Question

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Form Hypothesis

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Design and Perform Experiment

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Compare Predicted and Observed Results

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Draw Conclusions

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Form New Hypothesis and Repeat (if necessary)

Processes by which scientists generate and test hypotheses

Science is a body of knowledge systematically derived from study, observation, and experimentation. Its goal is to identify and establish principles and theories that may be applied to solve problems.

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.

Theory - principles or relationships which have been verified and accepted.

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

Hypothesis - an unproved theory or educated guess followed by research to best explain a phenomena. 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. The ability to collect data also limits scientific discovery. Scientists may interpret data differently on different occasions. These limitations mean that scientific explanations are changeable as new technologies emerge.

0003 Apply procedures related to the proper use of tools, equipment, and materials (including chemicals and living organisms) commonly used in biology, and practices for maintaining safety during biological investigations.

Knowledge of appropriate use of laboratory materials, tools, and equipment

Light microscopes are commonly used in high school laboratory experiments. Total magnification is the magnification of the ocular times the magnification of the objective lens. 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
- bringing the objective down to its lowest position when focusing and moving up to avoid breaking the slide or scratching the lens

To prepare **wet mount slides**, place a drop of water on the specimen and put 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 uses the principles of capillarity to separate substances such as plant pigments. Molecules of a larger size will move slower 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 an 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.

Spectrophotometry measures 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, while 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.

Storing, identifying, and disposing of chemicals and biological 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: Acrylonitriel, Arsenic compounds, Asbestos, Bensidine, Benzene, Cadmium compounds, Chloroform, Chromium compounds, Ethylene oxide, Ortho-toluidine, Nickle powder, and Mercury.

Chemicals should not be stored on bench tops or near 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.

Use of live specimens

No dissections may be performed on living mammalian vertebrates or birds. Lower order life and invertebrates may be used. Biological experiments may be done with all animals except mammalian vertebrates or birds. No physiological harm may result to the animal. All animals housed and cared for in the school must be handled in a safe and humane manner. Animals are not to remain on school premises during extended vacations unless adequate care is provided. Any instructor who intentionally refuses to comply with the laws may be suspended or dismissed.

Pathogenic organisms must never be used for experimentation. Students should adhere to the following rules at all times when working with microorganisms to avoid accidental contamination:

1. Treat all microorganisms as if they were pathogenic.
2. Maintain sterile conditions at all times.

Dissection and alternatives to dissection

Animals which were not obtained from recognized sources should not be used. Decaying animals or those of unknown origin may harbor pathogens and/or parasites. Specimens should be rinsed before handling. Latex gloves are recommended. If not available, students with sores or scratches should be excused from the activity. Formaldehyde is likely carcinogenic and should be avoided or disposed of according to district regulations. Students objecting to dissections for moral reasons should be given an alternative assignment. Interactive dissections are available online or from software companies for those students who object to performing dissections. There should be no penalty for those students who refuse to physically perform a dissection.

Laboratory safety procedures

All science labs should contain the following **safety equipment**.

- Fire blanket that is visible and accessible
- Ground Fault Circuit Interrupters (GFCI) within two feet of water supplies
- Signs designating room exits
- Emergency shower providing a continuous flow of water
- Emergency eye wash station that can be activated by the foot or forearm
- Eye protection for every student
- A means of sanitizing equipment
- Emergency exhaust fans providing ventilation to the outside of the building
- Master cut-off switches for gas, electric, and compressed air. Switches must have permanently attached handles. Cut-off switches must be clearly labeled
- An ABC fire extinguisher
- Storage cabinets for flammable materials
- Chemical spill control kit
- Fume hood with a motor that is spark proof
- Protective laboratory aprons made of flame retardant material
- Signs that will alert of potential hazardous conditions
- Labeled containers for broken glassware, flammables, corrosives, and waste

Students should wear safety goggles when performing dissections, heating, or while using acids and bases. Hair should always be tied back and objects should never be placed in the mouth. Food should not be consumed while in the laboratory. Hands should always be washed before and after laboratory experiments. In case of an accident, eye washes and showers should be used for eye contamination or a chemical spill that covers the student's body. Small chemical spills should only be contained and cleaned by the teacher. Kitty litter or a chemical spill kit should be used to clean a spill. For large spills, the school administration and the local fire department should be notified. Biological spills should only be handled by the teacher. Contamination with biological waste can be cleaned by using bleach when appropriate. Accidents and injuries should always be reported to the school administration and local health facilities. The severity of the accident or injury will determine the course of action.

It is the responsibility of the teacher to provide a safe environment for his or her students. Proper supervision greatly reduces the risk of injury and a teacher should never leave a class for any reason without providing alternate supervision. After an accident, two factors are considered, **foreseeability** and **negligence**. Foreseeability is the anticipation that an event may occur under certain circumstances. Negligence is the failure to exercise ordinary or reasonable care. Safety procedures should be a part of the science curriculum and a well managed classroom is important to avoid potential lawsuits.

0004 Understand historical and social aspects of biological study and contributions made to biology by various people.

Key events in the history of biological study

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, Louis Pasteur discovered the role of microorganisms in the cause of disease, pasteurization, and the rabies vaccine. Robert 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 all of the following criteria must be met to show that a microbe causes a disease.

1. The same pathogen must be found in every diseased organism but not in healthy organisms.
2. The pathogen must be isolated and grown in culture.
3. The pathogen must induce disease in experimental organisms.
4. The same pathogen must be isolated from the experimental organism.

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.

The debate about the ethical treatment of animals has been ongoing since the introduction of animals in research. Many people believe the use of animals in research is cruel and unnecessary. Animal use is federally and locally regulated. The purpose of the Institutional Animal Care and Use Committee (IACUC) is to oversee and evaluate all aspects of an institution's animal care and use program.

The impact of social factors on biological study

Society as a whole impacts biological research. Societal pressure has led to bans and restrictions on human cloning research. The United States government and the governments of many other countries have restricted human cloning. The U.S. legislature has banned the use of federal funds for the development of human cloning techniques. Some individual states have banned human cloning regardless of where the funds originate.

The demand for genetically modified crops by society and industry has steadily increased over the years. Genetic engineering in the agricultural field has led to improved crops for human use and consumption. Crops are genetically modified for increased growth and insect resistance because of the demand for larger and greater quantities of produce.

With advances in biotechnology come those in society who oppose it. Ethical questions come into play when discussing animal and human research. Does it need to be done? What are the effects on humans and animals? There are no absolute right or wrong answers to these questions. There are governmental agencies in place to regulate the use of humans and animals for research.

Science and technology are often referred to as a "double-edged sword". Although advances in medicine have greatly improved the quality and length of life, certain moral and ethical controversies have arisen. Unforeseen environmental problems may result from technological advances. Advances in science have led to an improved economy through biotechnology as applied to agriculture, yet it has put our health care system at risk and has caused the cost of medical care to skyrocket. Society depends on science, yet is necessary that the public be scientifically literate and informed in order to allow potentially unethical procedures to occur. Especially vulnerable are the areas of genetic research and fertility. It is important for science teachers to stay abreast of current research and to involve students in critical thinking and ethics whenever possible.