SUBAREA I. SCIENTIFIC INQUIRY AND THE HISTORY AND NATURE OF SCIENCE

COMPETENCY 1.0 UNDERSTAND THE NATURE OF SCIENCE AND THE PROCESSES AND PRINCIPLES OF SCIENTIFIC INQUIRY

Skill 1.1 Demonstrate an understanding of the nature, purpose, and distinguishing characteristics of science (e.g., the use of empirical standards, logical argument, skepticism) and limitations to the scope of science

The combination of science, mathematics and technology forms the scientific endeavor and makes science a success. It is impossible to study science on its own without the support of other disciplines like mathematics, technology, geology, physics, and other disciplines as well.

Science is tentative. By definition it is searching for information by making educated guesses. It must be replicable. Another scientist must be able to achieve the same results under the same conditions at a later time. The term empirical means it must be assessed through tests and observations. Science changes over time. Science is limited by the available technology. An example of this would be the relationship of the discovery of the cell and the invention of the microscope. As our technology improves, more hypotheses will become theories and possibly laws. Science is also limited by the data that is able to be collected. Data may be interpreted differently on different occasions. Science limitations cause explanations to be changeable as new technologies emerge. New technologies gather previously unavailable data and enable us to build upon current theories with new information.

Ancient history followed the geocentric theory, which was displaced by the heliocentric theory developed by Copernicus, Ptolemy and Kepler. Newton's laws of motion by Sir Isaac Newton were based on mass, force and acceleration, and state that the force of gravity between any two objects in the universe depends upon their mass and distance. These laws are still widely used today. In the 20th century, Albert Einstein was the most outstanding scientist for his work on relativity, which led to his theory that E=mc2. Early in the 20th century, Alfred Wegener proposed his theory of continental drift, stating that continents moved away from the super continent, Pangaea. This theory was accepted in 1960s when more evidence was collected on this. John Dalton and Lavosier made significant contributions in the field of the atom and matter. The Curies and Ernest Rutherford contributed greatly to radioactivity and the splitting of the atom, which have a lot of practical applications. Charles Darwin proposed his theory of evolution and Gregor Mendel's experiments on peas helped us to understand heredity. The most significant improvement was the Industrial Revolution in Britain, in which science was applied practically to increase the productivity and also introduced a number of social problems like child labor.

The nature of science mainly consists of three important things:

1. The scientific world view

This includes some very important issues like – it is possible to understand this highly organized world and its complexities with the help of latest the technology. Scientific ideas are subject to change. After repeated experiments, a theory is established, but this theory could be changed or supported in the future. Only laws that occur naturally do not change. Scientific knowledge may not be discarded but is modified – e.g., Albert Einstein didn't discard the Newtonian principles but modified them in his theory of relativity. Also, science can't answer all of our questions. We can't find answers to questions related to our beliefs, moral values, and our norms.

2. Scientific inquiry

Scientific inquiry starts with a simple question. This simple question leads to information gathering and an educated guess, otherwise known as a hypothesis. To prove the hypothesis, an experiment has to be conducted, which yields data and the conclusion. All experiments must be repeated at least twice to get reliable results. Thus scientific inquiry leads to new knowledge or verifying established theories. Science requires proof or evidence. Science is dependent on accuracy not bias or prejudice. In science, there is no place for preconceived ideas or premeditated results. By using their senses and modern technology, scientists will be able to get reliable information. Science is a combination of logic and imagination. A scientist needs to think and imagine and be able to reason.

Science explains, reasons and predicts. These three are interwoven and are inseparable. While reasoning is absolutely important for science, there should be no bias or prejudice. Science is not authoritarian because it has been shown that scientific authority can be wrong. No one can determine or make decisions for others on any issue.

3. Scientific enterprise

Science is a complex activity involving various people and places. A scientist may work alone or in a laboratory, classroom or for that matter anywhere. Mostly it is a group activity requiring a lot of social skills of cooperation, communication of results or findings, consultations and discussions. Science demands a high degree of communication to the governments, funding authorities and to the public.

Bias

Scientific research can be biased in the choice of what data to consider, in the reporting or recording of the data, and/or in how the data are interpreted. The scientist's emphasis may be influenced by his/her nationality, sex, ethnic origin, age, or political convictions. For example, when studying a group of animals, male scientists may focus on the social behavior of the males and typically male characteristics.

Although bias related to the investigator, the sample, the method, or the instrument may not be completely avoidable in every case, it is important to know the possible sources of bias and how bias could affect the evidence. Moreover, scientists need to be attentive to possible bias in their own work as well as that of other scientists.

Objectivity may not always be attained. However, one precaution that may be taken to guard against undetected bias is to have many different investigators or groups of investigators working on a project. By different, it is meant that the groups are made up of various nationalities, ethnic origins, ages, and political convictions and composed of both males and females. It is also important to note one's aspirations, and to make sure to be truthful to the data, even when grants, promotions, and notoriety are at risk.

Skill 1.2 Recognize the importance of verifiable evidence and peer review in science and that scientific hypotheses are subject to experimental and observational confirmation

Science is a process of checks and balances. It is expected that scientific findings will be challenged, and in many cases retested. Often one experiment will be the beginning point for another. While bias does exist, the use of controlled experiments and an awareness on the part of the scientist, can go far in ensuring a sound experiment. Even if the science is well done, it may still be questioned. It is through this continual search that hypotheses are made into theories, and sometimes become laws. It is also through this search that new information is discovered.

Skill 1.3 Demonstrate knowledge of scientific methods and apply principles and procedures for designing and conducting scientific investigations (e.g., identifying constants, manipulated and responding variables; sampling)

The scientific method is the basic process behind science. It involves several steps beginning with hypothesis formulation and working through to the conclusion.

Posing a question
Although many discoveries happen by chance, the standard thought process of a scientist begins with forming a question to research. The more limited the question, the easier it is to set up an experiment to answer it.

Form a hypothesis
Once the question is formulated take an educated guess about the answer to the problem or question. This 'best guess' is your hypothesis.

Conducting the test
To make a test fair, data from an experiment must have a variable or any condition that can be changed such as temperature or mass. A good test will try to manipulate as few variables as possible so as to see which variable is responsible for the result. This requires a second example of a control. A control is an extra setup in which all the conditions are the same except for the variable being tested.

Observe and record the data
Reporting of the data should state specifics of how the measurements were calculated. A graduated cylinder needs to be read with proper procedures. As beginning students, technique must be part of the instructional process so as to give validity to the data.

Drawing a conclusion
After recording data, you compare your data with that of other groups. A conclusion is the judgment derived from the data results.

Graphing data
Graphing utilizes numbers to demonstrate patterns. The patterns offer a visual representation, making it easier to draw conclusions.

Normally, knowledge is integrated in the form of a lab report. A report has many sections. It should include a specific title and tell exactly what is being studied. The abstract is a summary of the report written at the beginning of the paper. The purpose should always be defined and will state the problem. The purpose should include the hypothesis (educated guess) of what is expected from the outcome of the experiment. The entire experiment should relate to this problem. It is important to describe exactly what was done to prove or disprove a hypothesis. A control is necessary to prove that the results occurred from the changed conditions and would not have happened normally. Only one variable should be manipulated at a time. Observations and results of the experiment should be recorded including data from all results. Drawings, graphs and illustrations should be included to support information. Observations are objective, whereas analysis and interpretation is subjective. A conclusion should explain why the results of the experiment either proved or disproved the hypothesis. A scientific theory is an explanation of a set of related observations based on a proven hypothesis. A scientific law usually lasts longer than a scientific theory and has more experimental data to support it.

Sampling

Sampling is collecting pieces/specimens or making instrument data points/observations at determined intervals or areas for the purpose of research/investigation. Sampling includes animal tracking, capturing, plant and animal tagging, plot sampling, specimen collecting, transect sampling, water sampling etc. The results obtained are used as representative of the whole research area or population.

Skill 1.4 Identify the characteristics and uses of various types of scientific investigations (e.g., controlled experiments, field observations) and evaluate the appropriateness of a given investigative design for testing a particular hypothesis

Scientific investigations come in all sizes and forms. One can conduct a simple survey, over the course of a large population, with the hopes of gaining an understanding of the entire population. This method is often used by medical and pharmaceutical companies and may include a questionnaire that asks about health and lifestyle. Ecologists use field observations. Like the medical questionnaire, they study small sample sizes to gain a better understanding of a larger group. For example, they may track one animal to follow its migratory patterns, or they may place cameras in one area in the hopes of capturing footage of a roaming animal or pack. Ecologists are studying an area and all of the organisms within it, but this is too broad to study, so they often limit sampling size and use a representative of the population. Whenever possible, a scientist would prefer to use controlled experiments. This can happen most readily in a laboratory, and is near impossible to achieve in nature. In a controlled experiment, only one variable is manipulated at once, and a control, or normal variable under normal conditions, is always present. This control group gives the scientist something to compare the variable against. It tells him what would normally have happened under the experimental conditions, had he not altered/introduced the variable.

An experiment is proposed and performed with the sole objective of testing a hypothesis. When evaluating an experiment, it is important to first look at the question it was supposed to answer. How logically did the experiment flow from there? How many variables existed? (it is best to only test one variable at a time) You discover a scientist conducting an experiment with the following characteristics. He has two rows each set up with four stations. The first row has a piece of tile as the base at each station. The second row has a piece of linoleum as the base at each station. The scientist has eight eggs and is prepared to drop one over each station. What is he testing? He is trying to answer whether or not the egg is more likely to break when dropped over one material as opposed to the other. His hypothesis might have been: The egg will be less likely to break when dropped on linoleum. This is a simple experiment. If the experiment was more complicated, or for example, conducted on a microscopic level, one might want to examine the appropriateness of the instruments utilized and their calibration.

Properly collecting data yields information that appropriately answers the original question. For example, one wouldn’t try use a graduated cylinder to measure mass, nor would one use a ruler to measure a microscopic item. Utilizing appropriate measuring devices, using proper units, and careful mathematics will provide strong results. Carefully evaluating and analyzing the data creates a reasonable conclusion. The conclusion needs to be backed up by scientific criteria, then, finally, communicated to the audience.

Skill 1.5 Identify sources of error or uncertainty in an investigation

Unavoidable experimental error is the random error inherent in scientific experiments regardless of the methods used. One source of unavoidable error is measurement and the use of measurement devices. Using measurement devices is an imprecise process because it is often impossible to accurately read measurements. For example, when using a ruler to measure the length of an object, if the length falls between markings on the ruler, we must estimate the true value. Another source of unavoidable error is the randomness of population sampling and the behavior of any random variable. For example, when sampling a population we cannot guarantee that our sample is completely representative of the larger population. In addition, because we cannot constantly monitor the behavior of a random variable, any observations necessarily contain some level of unavoidable error.

Statistical variability is the deviation of an individual in a population from the mean of the population. Variability is inherent in biology because living things are innately unique. For example, the individual weights of humans vary greatly from the mean weight of the population. Thus, when conducting experiments involving the study of living things, we must control for innate variability. Control groups are identical to the experimental group in every way with the exception of the variable being studied. Comparing the experimental group to the control group allows us to determine the effects of the manipulated variable in relation to statistical variability.

COMPETENCY 2.0 UNDERSTAND PROCEDURES FOR GATHERING, RECORDING, ORGANIZING, INTERPRETING, ANALYZING, AND COMMUNICATING SCIENTIFIC DATA AND INFORMATION

Skill 2.1 Use appropriate methods, tools, and technologies for gathering, recording, processing, analyzing, and evaluating data and for communicating the results of scientific investigations

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 conditions. The variable includes a factor that is changed. In biology, the variable may be light, temperature, pH, time, etc. The differences in tested variables may be used to make a prediction or form a hypothesis. Only one variable should be tested at a time. One would not alter both the temperature and pH of the experimental subject.

An **independent variable** is one that is changed or manipulated by the researcher. This could be the amount of light given to a plant or the temperature at which bacteria is grown. The **dependent variable** is that which is influenced by the independent variable.

Measurements may be taken in different ways. There is an appropriate measuring device for each aspect of biology. A graduated cylinder is used to measure volume. A balance is used to measure mass. A microscope is used to view microscopic objects. A centrifuge is used to separate two or more parts in a liquid sample. The list goes on, but you get the point. For each variable, there is an appropriate way to measure it. The Internet and teaching guides are virtually unlimited resources for laboratory ideas. You should be imparting on the students the importance of the method with which they conduct the study, the resource they use to do so, the concept of double checking their work, and the use of appropriate units.

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.

Skill 2.2 Select appropriate methods and criteria for organizing and displaying data (e.g., tables, graphs, models)

Graphing data
Graphing utilizes numbers to demonstrate patterns. The patterns offer a visual representation, making it easier to draw conclusions.

Graphing is an important skill to visually display collected data for analysis. The two types of graphs most commonly used are the line graph and the bar graph (histogram). Line graphs are set up to show two variables represented by one point on the graph. The X axis is the horizontal axis and represents the independent variable. Independent variables are those that would be present independently of the experiment. A common example of an jndependent variable is time. Time proceeds regardless of anything else that may be occurring. The Y axis is the vertical axis and represents the dependent variable. Dependent variables are manipulated by the experiment, such as the amount of light, or the height of a plant. Graphs should be calibrated at equal intervals. If one space represents one day, the next space may not represent ten days. A "best fit" line is drawn to join the points and may not include all the points in the data. Axes must always be labeled for the graph to be meaningful. A good title will describe both the dependent and the independent variable. Bar graphs are set up similarly in regards to axes, but points are not plotted. Instead, the dependent variable is set up as a bar where the X axis intersects with the Y axis. Each bar is a separate item of data and is not joined by a continuous line.

Skill 2.3 Demonstrate an understanding of the concepts of precision, accuracy, and error with regard to gathering and recording scientific data

Accuracy is the degree of conformity of a measured, calculated quantity to its actual (true) value. Precision, also called reproducibility or repeatability, is the degree to which further measurements or calculations will show the same or similar results.

Accuracy is the degree of veracity while precision is the degree of reproducibility. The best analogy to explain accuracy and precision is the target comparison.

Repeated measurements are compared to arrows that are fired at a target. Accuracy describes the closeness of arrows to the bull's eye at the target center. Arrows that strike closer to the bull's eye are considered more accurate.

All experimental uncertainty is due to either random errors or systematic errors.

Random errors are statistical fluctuations in the measured data due to the precision limitations of the measurement device. Random errors usually result from the experimenter's inability to take the same measurement in exactly the same way to get exactly the same number.

Systematic errors, by contrast, are reproducible inaccuracies that are consistently in the same direction. Systematic errors are often due to a problem which persists throughout the entire experiment.

Systematic and random errors refer to problems associated with making measurements. Mistakes made in the calculations or in reading the instrument are not considered in error analysis.

Skill 2.4 Demonstrate knowledge of the measurement units used in scientific investigations

Science uses the metric system as it is accepted worldwide and allows easier comparison among experiments done by scientists around the world. Learn the following basic units and prefixes:

meter - measure of length
liter - measure of volume
gram - measure of mass

deca-(meter, liter, gram) = 10X the base unit	deci = 1/10 the base unit
hecto-(meter, liter, gram) = 100X the base unit	centi= 1/100 the base unit
kilo-(meter, liter, gram) = 1000X the base unit	milli= 1/1000 the base unit

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

The common instrument used is measuring mass is the triple beam balance. The triple beam balance is measured in as low as tenths of a gram and can be estimated to the hundredths of a gram.

The ruler or meter stick is the most commonly used instrument for measuring length. Measurements in science should always be measured in metric units. Be sure when measuring length that the metric units are used.

Skill 2.5 Identify and evaluate various sources of scientific information (e.g., handbooks, professional journals, popular press, the Internet, community-based resources)

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 (advertisers, debaters, etc.) often overemphasize the certainty and importance of experimental results. One should question any scientific claim that sounds fantastical 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.