

## **SUBAREA I.**

## **FOUNDATIONS OF SCIENTIFIC INQUIRY**

### **COMPETENCY 1.0 UNDERSTAND THE PRINCIPLES AND PROCEDURES FOR CONDUCTING SCIENTIFIC RESEARCH.**

#### **Skill 1.1 Developing valid experimental designs for collecting data and testing hypotheses**

Science may be defined as a body of knowledge that is 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, is a belief that is not warranted. There is no scientific methodology or application. Some of the more classic examples of pseudoscience include astrology, the occult, and phrenology.

Scientific theory and experimentation must be repeatable. It is also possible to be disproved and is capable of change. Science depends on communication, agreement, and disagreement among scientists. It is composed of theories, laws, and hypotheses.

theory - the formation of 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.

The first step in scientific inquiry is posing a question to be answered. 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 the process is repeated.

## **Skill 1.2 Recognizing the role of control groups in experiments**

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. For example, one would not alter both the temperature and pH of the experimental subject.

## **Skill 1.3 Understanding procedures for collecting and interpreting data to minimize bias**

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.

For these reasons, and many more, 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 1.4 Identifying procedures used in setting up and conducting scientific investigations in the field and in the laboratory**

Light microscopes are commonly used in high school laboratory experiments. Total magnification is determined by multiplying the ocular (usually 10X) and the objective (usually 10X on low, 40X on high) lenses. Several procedures should be followed to properly care for this equipment.

- Clean all lenses with lens paper only.
- Carry microscopes with two hands; one on the arm and one on the base.
- Always begin focusing on low power, then switch to high power.
- Store microscopes with the low power objective down.
- Always use a coverslip when viewing wet mount slides.
- Bring the objective down to its lowest position then focus moving upwards 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 in avoiding 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, 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.

All science labs should contain the following items of safety equipment. Those marked with an asterisk are required by state laws.

- \* fire blanket which is visible and accessible
- \*Ground Fault Circuit Interrupters (GCFI) within two feet of water supplies
- \*signs designating room exits
- \*emergency shower providing a continuous flow of water
- \*emergency eye wash station which can be activated by the foot or forearm
- \*eye protection for every student and 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 which is spark proof
- \*protective laboratory aprons made of flame retardant material
- \*signs which will alert 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 spills. For large spills, the school administration and the local fire department should be notified. Biological spills should also be handled only 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 to pursue.

It is the responsibility of the teacher to provide a safe environment for their 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.

**Skill 1.5 Recognizing variables being held constant, being manipulated (i.e., independent variables), and responding (i.e., dependent variables)**

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; it responds to the independent variable. If there are multiple variables, and you choose to study only one, then the variables unchanged are said to be held constant. For example, you might study multiple objects, each with the same size and shape (volume is constant), but differing in density.

**Skill 1.6 Identifying the most effective method for presenting data for a given purpose (e.g., graph, table, map)**

The type of graphic representation used to display observations depends on the data that is collected. Line graphs are used to compare different sets of related data or to predict data that has not yet be measured. An example of a line graph would be comparing the rate of activity of different enzymes at varying temperatures. A bar graph or histogram is used to compare different items and make comparisons based on this data. An example of a bar graph would be comparing the ages of children in a classroom. A pie chart is useful when organizing data as part of a whole. A good use for a pie chart would be displaying the percent of time students spend on various after school activities.

As noted before, the independent variable is controlled by the experimenter. This 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 take the largest value to be plotted and divide it by the number of block, and rounding to the nearest whole number.

## Skill 1.7 Evaluating simple descriptive statistics

Simple descriptive statistics are meant to describe features of data in a study. This is a description of what was observed or what the data shows. It is not meant to infer anything further, nor does it speculate about what may be. Descriptive Statistics are used to present quantitative descriptions in a manageable form. Consider the infamous the Grade Point Average (GPA). The single number assigned describes a large number of grades, one per each class ever taken. The GPA describes the general performance of the student. While condensing large amounts of information, the danger in descriptive statistics is that the whole picture can become less clear. For example, we don't know if the student had a high GPA because s/he took relatively easy courses, or if the student never took a biology class in their whole collegiate career. There is potentially a wider range of experiences than is encompassed in a descriptive statistic. One should keep this in mind when evaluating a situation or material when only a simple descriptive statistic is provided.

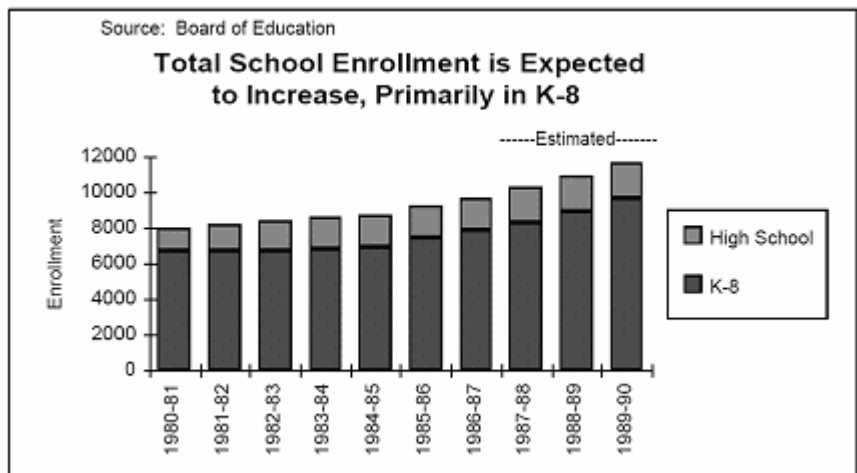
## Skill 1.8 Interpreting data presented in different formats

Data collected is initially organized into tables. Trends or patterns in data can be difficult to identify using tables of numbers. However, more often than not, the data is compiled into graphs. Graphs help scientists visualize and interpret the variation in data. Depending on the nature of the data, there are many types of graphs. Bar graphs, pie charts and line graphs are just a few methods used to pictorially represent numerical data. There are six basic types of graphs.

### Column Graphs

Column graphs consist of patterned rectangles displayed along a baseline called the x-category or the horizontal axis. The height of the rectangle represents the amount of data. Column graphs best show:

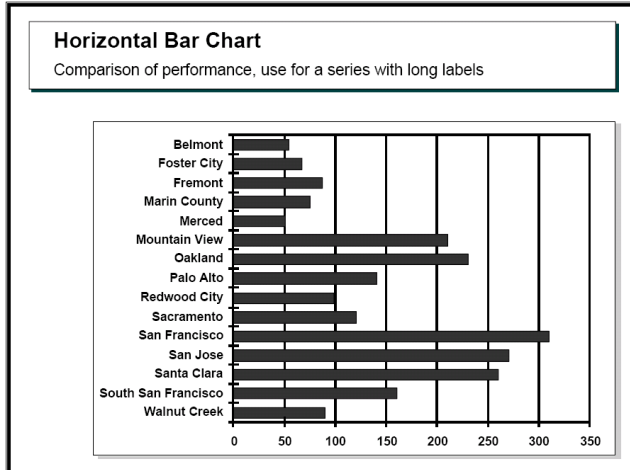
- changes in data over time (short time series)
- comparisons of several items (relationship between two series)



## Bar Graphs

Column graphs can be described as rectangles that are arranged horizontally. The length of each rectangle represents its value. Bar graphs are sometimes referred to as histograms. Bar graphs best show:

- data series with no natural order.



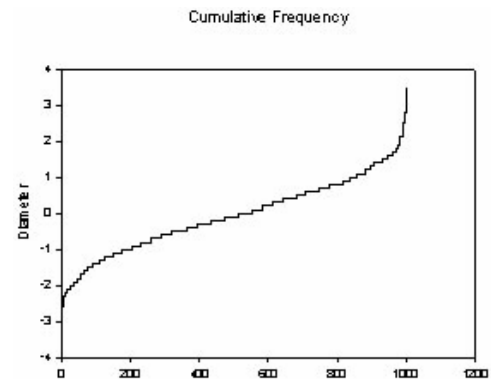
Bar graphs are good for looking at differences amongst similar things. If the data are a time series, a carefully chosen column graph is generally more appropriate but bar graphs can be used to vary a presentation when many column graphs of time series are used. One advantage of bar graphs is that there is greater horizontal space for variable descriptors because the vertical axis is the category axis.

## Line Graphs

Line graphs show data points connected by lines; different series are given different line markings (for example, dashed or dotted) or different tick marks. Line graphs are useful when the data points are more important than the transitions between them. They best show:

- the comparison of long series
- a general trend is the message.

Line graphs are good for showing trends or changes over time.

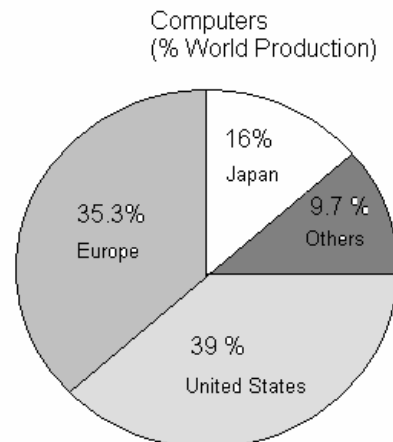


## Pie Charts

A pie chart is a circle with radii connecting the center to the edge. The area between two radii is called a slice. Data values are proportionate to the angle between the radii. Pie charts best show:

- parts of a whole

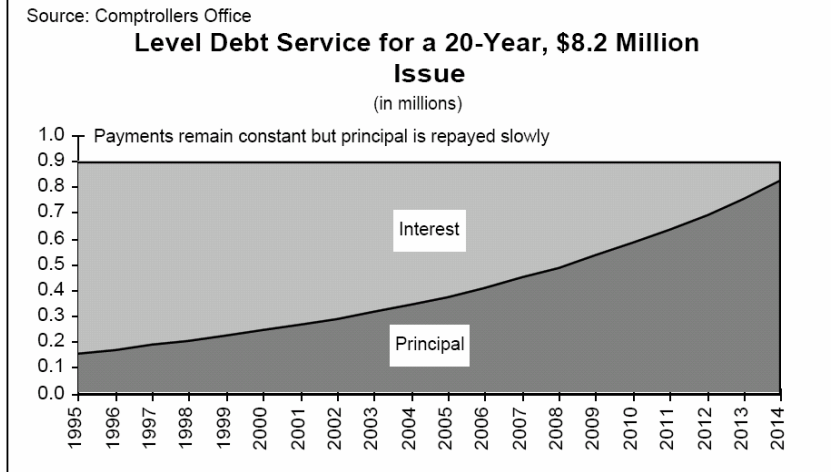
Be careful of too many slices since they result in a cluttered graph. Six slices is the general rule as to how many slices can be handled on one pie.



## Area Graphs

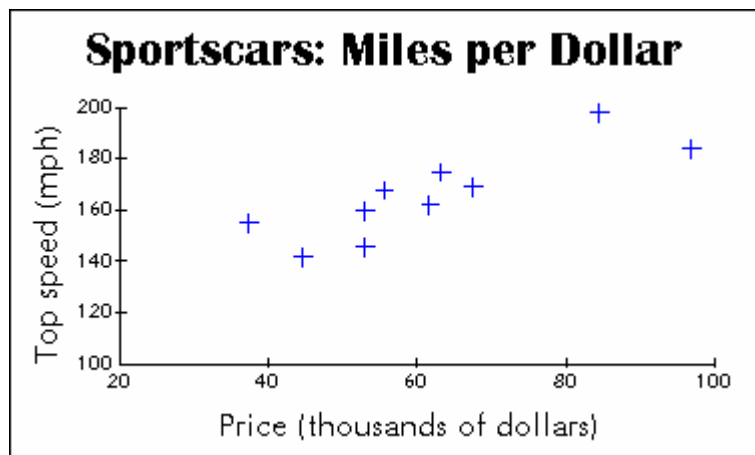
Area charts show the relative contributions over time that each data series makes to a whole picture and are “stacked line graphs” in the sense that values are added to the variables below. Unlike line graphs, the space between lines is filled with shadings. Area graphs are similar to line graphs with the added drama of shading between lines to

emphasize variation between whatever the lines represent. They differ from line graphs in that the shaded areas are “added” one on top of the next. Thus, the scale provides accurate measurements only for the lowest part of the graph. This can cause misinterpretation if not fully understood. If reasonable, consider putting the “flattest” graph on the bottom.



## Scatter Graphs

A scatter plot is the simplest type of graph. It simply plots the data points against their values, without adding an connecting lines, bars or other stuff. The first variable is measured along the x-axis and the second along the y-axis. Because of this, scatter graphs do not have descriptors in the same sense as other graphs.



Scatter graphs best show possible relationships between two variables. The purpose of the graph is to try to decide if some partial or indirect relationship—a correlation—exists.

### **Skill 1.9      Evaluating the validity of conclusions; and assessing the reliability of sources of information**

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.

