COMPETENCY 1.0 KNOWLEDGE OF THE NATURE OF SCIENCE

Skill 1.1 Analyze processes of scientific inquiry.

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 involved. Some of the more classic examples of pseudoscience include witchcraft, alien encounters, or any topics that are explained by hearsay.

Scientific inquiry starts with observation. After observing, a question is formed, which starts with “why” or “how.” To answer these questions, experimentation is necessary. Between observation and experimentation, there are three more important steps. These are: gathering information (or researching about the problem), stating a hypothesis, and designing the experiment.

Designing an experiment involves identifying controls, constants, independent variables and dependent variables. A control or standard is something we compare our results with at the end of the experiment. It is like a reference. Constants are the factors we keep constant in an experiment to get reliable results. Independent variables are factors we change in the experiment. It is important to remember that there should be more constants than variables to obtain reproducible results in an experiment.

Classifying is grouping items according to their similarities. It is important for students to realize relationships and similarity as well as differences to reach a reasonable conclusion in a lab experience.

After the experiment is completed, it is repeated and results are graphically presented. The results are then analyzed and conclusions drawn.

After the conclusion is drawn, the final step is communication. In this age, a lot of emphasis is put on the method of communication. The conclusions must be communicated by clearly describing the information using accurate data, visual presentation (such as bar, line, or pie graphs), tables/charts, diagrams, artwork, and other appropriate media, such as a Power Point presentation. Modern technology must be used whenever it is necessary. The method of communication must be suitable to the audience.

Written communication is as important as oral communication. This is essential for submitting research papers to scientific journals, newspapers, magazines, etc.

Skill 1.2 Evaluate models used in science to explain patterns observed in nature (e.g., rock cycle, heliocentric, geocentric, nitrogen cycle, water cycle).

A **model** is a basic element of scientific inquiry. Many phenomena in science are studied with models. A model is a simplification or representation of a problem that is being studied or predicted. A model is a substitute, but it is similar to what it represents. We use models to describe the solar system, explain how Earth materials are recycled, illustrate the structure of an atom, and more. Physicists use Newton's laws to predict how objects will interact, such as planets and spaceships. In geology, the continental drift model estimates the past positions of continents. At every step of scientific study, models are extensively used. The primary activity of hundreds of thousands of U.S. scientists is to produce new models; these models are presented to the scientific community and the general public in tens of thousands of scientific papers published every year.

Some examples of scientific models:

The **rock cycle** is a model that describes the various complex geologic processes that create, destroy, and modify rocks. The rock cycle model represents the ways in which rocks are continually modified, changing between igneous, sedimentary, and metamorphic, as they move through the cycle. For example, igneous rocks are those created by magma. Igneous rocks exposed at the surface may be broken down by erosion. The resultant sediments may later become lithified, turning into sedimentary rocks. Igneous or sedimentary rocks that are exposed to extreme heat and pressure beneath Earth’s crust undergo changes without melting—these are metamorphic rocks. As the rock cycle illustrates, any type of rock can be changed into any other type, if the conditions are right. In this sense, no rocks are truly created or destroyed, since they are all constantly being recycled.

The **heliocentric** model is the one that we currently use to describe our solar system. Heliocentric refers to the fact that in this model, the Sun is at the center. Prior to the development and acceptance of the heliocentric model, people believed the **geocentric** model (Earth at the center) correctly represented the solar system.

The **nitrogen cycle** is a model used to represent the movement of nitrogen through the atmosphere, geosphere, and biosphere. The main processes involved in the nitrogen cycle are nitrogen fixation, nitrogen uptake, nitrogen mineralization, nitrification, and denitrification. Nitrogen fixation refers to the conversion of nitrogen in its gaseous form (by bacteria) to a form useable by plants. Nitrogen uptake occurs when plants absorb nitrogen from the soil, after hit has been "fixed." Nitrogen mineralization refers to the process by which organic nitrogen from decaying plant and animal matter is converted to ammonia and ammonium. Nitrification is the process by which bacteria transform ammonia to nitrite and nitrate, which can be taken up by plants. Lastly, denitrification changes oxidized forms of nitrogen (such as nitrite and nitrate) into dinitrogen (N_2) and nitrous oxide gas.

The **water cycle**, or **hydrologic cycle**, is a model used to represent the cycling of water through the atmosphere, geosphere, hydrosphere, and biosphere. The water cycle models the movement of water between storage areas (such as clouds, lakes, oceans, ice caps, etc.) through processes including evaporation, condensation, precipitation, runoff, groundwater discharge, sublimation, and evapotranspiration.

Skill 1.3 Identify the influences of science and society on each other.

Science and society are closely intertwined. The influence of social and cultural factors on science is profound. In a way, we can say that society has changed the face of science by absorbing scientific innovations. Science has always been a significant part of society. In ancient societies, people did not conceptualize science but took it as a part of their lives. In the modern society, everything has a label and a name, so people are aware of science and other disciplines.

Societies have had trouble accepting science, especially where the science exposed some cultural aspects as myths. A dilemma was created: whether to accept the proven facts provided by scientific investigations or cling to cultural norms. This went on for centuries. It took a long time for societies to accept scientific facts and leave behind some cultural practices, or to modify them. There are two main groups—cultural practices by societies which are scientifically correct and cultural practices which have no scientific foundation (myths and superstitions). A society's progress depends on distinguishing between these two. Some indigenous societies suffered when they were not quick to adjust, since their cultures are very ancient and people found it difficult to accept new challenges and adapt to new changes. At the same time, ancient cultures like the Chinese, Egyptian, Greek, Asian, and Indian were scientifically advanced, as was recorded in their writings.

If we compare science to a volcano, technology is like lava spewing out of the volcano. This was the scenario in the last few centuries in terms of rapid strides in the development of technology. Technology greatly influenced society and culture. At the same time, like a two-way street, science and culture exercised their influence on technology.

Although available, even today some cultures are not using modern technology. Other cultures have so readily adapted to technology that lives are inundated with it. Our lives have become intertwined with technology so much that we utilize the computer, television, microwave, dishwasher, washing machine, cell phone, etc. on a daily basis. Cultures that are not in tune with modern technology are falling behind. It is often argued that to live without technology yields peace of mind, serenity and happiness, but it also results in the loss of valuable opportunities in this age of communication.

Technology has revolutionized education, medicine, communication, and travel. Additionally, technology has provided methods of global to the extent that the planet has seemed to shrink; it is now possible to communicate with almost anyone, anywhere, in a matter of seconds.

Skill 1.4 Analyze the synergistic relationships between basic and applied research, technology, the economy, and the public good.

The relationship among basic and applied research, technology, the economy, and society is such that each is interdependent on the others. Basic research is the starting point in this chain of events. Basic research provides knowledge, which is of two types. The first type of knowledge is theoretical knowledge, giving us the understanding of processes. The second type of knowledge could be applied for the benefit of humanity. Applied research is valuable because it is directly useful to us; it deals with issues like AIDS, Tuberculosis, HPV, Parkinson’s Disease, etc. This is important to society because it is useful to the public. Citizens are interested in it and public has its own opinions about the research. As an example, let’s look at stem cell research. There are people for and against this controversial piece of research. We are living in the age of technology. We are afraid that we may not be able to function without technology. Such is the relationship of society with technology. The economy, technology and public are inseparable, in that our money, comforts, and modern knowledge are so intertwined with each of these three fields.

This synergistic relationship overlaps some moral and ethical issues. Whatever research is done, public has a right to know it. The economy should not be the guiding force for any piece of research or technology. Clear objectives are critical because the public has a stake in these ventures, especially if they are federally funded. If they are privately funded, the organizations need to remember that they are bound by social ethics and correct practices.

The ultimate goal of any research, technology project, or economic venture must be for the benefit of public.

Skill 1.5 Evaluate the appropriate use of inferences, assumptions, observations, hypotheses, conclusions, laws, and theories.

Inference – the conclusion that something is true in light of something else being or seeming true. An inference can be correct or incorrect.

Assumption – an idea whose truth is taken for granted as fact, even though it may not be. An assumption can be correct or incorrect.

Observation – when one perceives activity and records that activity.

Hypothesis - an unproved theory or educated guess to best explain a phenomena. The validity of a hypothesis may be tested through research.

Conclusion – takes into account observations, data, and previous information to make a logical statement about what has occurred. May also define what steps should be taken next.

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

Theory – the formation of principles or relationships which have been verified and accepted. A theory is a proven hypothesis.

Skill 1.6 Analyze scientific data presented in tables, graphs, and diagrams.

When first collected, data are initially organized into tables, spreadsheets, or databases. For example, the table below presents carbon dioxide concentrations taken over many years atop the Mauna Loa Observatory in Hawaii.

Atmospheric CO_2 concentrations at Mauna Loa

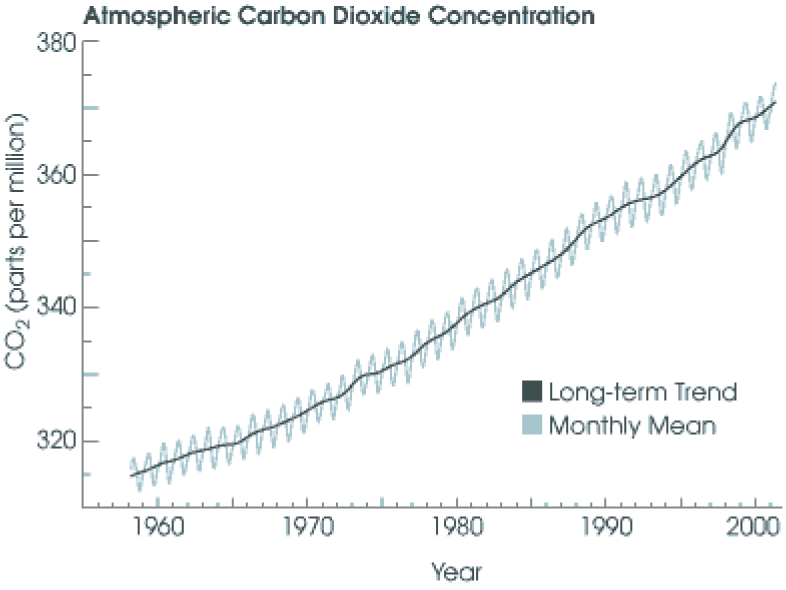
(CDIAC- Carbon Dioxide Information Analysis Center)

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1958	--	--	315.71	317.45	317.50	--	315.86	314.93	313.19	--	313.34	314.67	--
1959	315.58	316.47	316.65	317.71	318.29	318.16	316.55	314.80	313.84	313.34	314.81	315.59	315.98
1960	316.43	316.97	317.58	319.03	320.03	319.59	318.18	315.91	314.16	313.83	315.00	316.19	316.91
1961	316.89	317.70	318.54	319.48	320.58	319.78	318.58	316.79	314.99	315.31	316.10	317.01	317.65
1962	317.94	318.56	319.69	320.58	321.01	320.61	319.61	317.40	316.26	315.42	316.69	317.69	318.45
1963	318.74	319.08	319.86	321.39	322.24	321.47	319.74	317.77	316.21	315.99	317.07	318.36	318.99
1964	319.57	--	--	--	322.23	321.89	320.44	318.70	316.70	316.87	317.68	318.71	--
1965	319.44	320.44	320.89	322.13	322.16	321.87	321.21	318.87	317.81	317.30	318.87	319.42	320.03
1966	320.62	321.59	322.39	323.70	324.07	323.75	322.40	320.37	318.64	318.10	319.79	321.03	321.37
1967	322.33	322.50	323.04	324.42	325.00	324.09	322.55	320.92	319.26	319.39	320.72	321.96	322.18
1968	322.57	323.15	323.89	325.02	325.57	325.36	324.14	322.11	320.33	320.25	321.32	322.90	323.05
1969	324.00	324.42	325.64	326.66	327.38	326.70	325.89	323.67	322.38	321.78	322.85	324.12	324.62
1970	325.06	325.98	326.93	328.13	328.07	327.66	326.35	324.69	323.10	323.07	324.01	325.13	325.68
1971	326.17	326.68	327.18	327.78	328.92	328.57	327.37	325.43	323.36	323.56	324.80	326.01	326.32
1972	326.77	327.63	327.75	329.72	330.07	329.09	328.05	326.32	324.84	325.20	326.50	327.55	327.46
1973	328.54	329.56	330.30	331.50	332.48	332.07	330.87	329.31	327.51	327.18	328.16	328.64	329.68
1974	329.35	330.71	331.48	332.65	333.09	332.25	331.18	329.40	327.44	327.37	328.46	329.58	330.25
1975	330.40	331.41	332.04	333.31	333.96	333.59	331.91	330.06	328.56	328.34	329.49	330.76	331.15
1976	331.74	332.56	333.50	334.58	334.87	334.34	333.05	330.94	329.30	328.94	330.31	331.68	332.15
1977	332.92	333.42	334.70	336.07	336.74	336.27	334.93	332.75	331.58	331.16	332.40	333.85	333.90
1978	334.97	335.39	336.64	337.76	338.01	337.89	336.54	334.68	332.76	332.54	333.92	334.95	335.50
1979	336.23	336.76	337.96	338.89	339.47	339.29	337.73	336.09	333.91	333.86	335.29	336.73	336.85
1980	338.01	338.36	340.08	340.77	341.46	341.17	339.56	337.60	335.88	336.01	337.10	338.21	338.69
1981	339.23	340.47	341.38	342.51	342.91	342.25	340.49	338.43	336.69	336.85	338.36	339.61	339.93
1982	340.75	341.61	342.70	343.56	344.13	343.35	342.06	339.82	337.97	337.86	339.26	340.49	341.13
1983	341.37	342.52	343.10	344.94	345.75	345.32	343.99	342.39	339.86	339.99	341.16	342.99	342.78
1984	343.70	344.51	345.28	347.08	347.43	346.79	345.40	343.28	341.07	341.35	342.98	344.22	344.42
1985	344.97	346.00	347.43	348.35	348.93	348.25	346.56	344.69	343.09	342.80	344.24	345.56	345.90
1986	346.29	346.96	347.86	349.55	350.21	349.54	347.94	345.91	344.86	344.17	345.66	346.90	347.15
1987	348.02	348.47	349.42	350.99	351.84	351.25	349.52	348.10	346.44	346.36	347.81	348.96	348.93
1988	350.43	351.72	352.22	353.59	354.22	353.79	352.39	350.44	348.72	348.88	350.07	351.34	351.48
1989	352.76	353.07	353.68	355.42	355.67	355.13	353.90	351.67	349.80	349.99	351.30	352.53	352.91
1990	353.66	354.70	355.39	356.20	357.16	356.22	354.82	352.91	350.96	351.18	352.83	354.21	354.19
1991	354.72	355.75	357.16	358.60	359.34	358.24	356.17	354.03	352.16	352.21	353.75	354.99	355.59
1992	355.98	356.72	357.81	359.15	359.66	359.25	357.03	355.00	353.01	353.31	354.16	355.40	356.37
1993	356.70	357.16	358.38	359.46	360.28	359.60	357.57	355.52	353.70	353.98	355.33	356.80	357.04
1994	358.36	358.91	359.97	361.26	361.68	360.95	359.55	357.49	355.84	355.99	357.58	359.04	358.88
1995	359.96	361.00	361.64	363.45	363.79	363.26	361.90	359.46	358.06	357.75	359.56	360.70	360.88
1996	362.05	363.25	364.03	364.72	365.41	364.97	363.65	361.49	359.46	359.60	360.76	362.33	362.64
1997	363.18	364.00	364.57	366.35	366.79	365.62	364.47	362.51	360.19	360.77	362.43	364.28	363.76
1998	365.32	366.15	367.31	368.61	369.30	368.87	367.64	365.77	363.90	364.23	365.46	366.97	366.63
1999	368.15	368.86	369.58	371.12	370.97	370.33	369.25	366.91	364.60	365.09	366.63	367.96	368.29
2000	369.08	369.40	370.45	371.59	371.75	371.62	370.04	368.04	366.54	366.63	368.20	369.43	369.40
2001	370.17	371.39	372.00	372.75	373.88	373.17	371.48	369.42	367.83	367.96	369.55	371.10	370.89
2002	372.29	372.94	373.38	374.71	375.40	375.26	373.87	371.35	370.57	370.10	371.93	373.63	372.95

Looking at this table of data in various ways we can make several observations, with the help of a calculator:

- **Data completeness –** There are some gaps in the data between 1958 and 1964. From 1965 on, observations of CO_2 levels in the atmosphere have been made consistently every month.
- **Seasonal effects –** Looking across the rows of data, we can identify seasonal trends within years. For example, we can see that the highest concentrations tend to be in April, May, and June and the lowest concentrations tend to be in September and October. The difference appears to be about 4-5 ppm.
- **Long term trends –** Looking down the columns of data, we can evaluate long-term trends over the years shown. In every month, concentrations of CO_2 have risen approximately 58 ppm over 45 years, or about 1.3 ppm/yr.

While these trends can be observed using tables, it is much easier when the data are then compiled into graphs or charts. Graphs help scientists visualize and interpret variations and patterns in data. The following is the same set of data as a line graph. This is a famous graph called the Keeling Curve (courtesy NASA).



In the graph, the x-axis represents time in units of years and the y-axis represents CO_2 concentration in units of parts per million (ppm). The best fit line (solid dark line) shows the trend in CO_2 concentration during the time period shown. This steady upward-sloping line indicates an overall trend of increasing CO_2 concentration between 1958 and 2002. The light blue line, which indicates monthly mean CO_2 levels, shows the periodic variation in CO_2 concentrations during each year. Either the table or the graph can be used to predict future trends in the data.

Example: If CO_2 emission trends continue roughly as they have over the last 40 years, what will be the estimated CO_2 concentration in the atmosphere in 2020?

Solution: The average concentration of CO_2 in 2002 is listed in the table in the right-hand column, and is 372.95 ppm. 18 yrs multiplied by an average increase of about 1.3 ppm/yr = 23.4 ppm increase by 2020, for a total concentration of about 396.4 ppm CO_2.

Skill 1.7 Differentiate between qualitative and quantitative data in experimental, observational, and modeling methods of research.

Quantitative is derived from quantity (numerical, precise) and qualitative (impressive) is derived from quality. Qualitative and quantitative data can be compared and differentiated as follows:

1. Assumptions:
In quantitative experimentation, the method is of primary importance. Variables are identified and relationships are measured. In qualitative experimentation, subject matter is of prime importance. Variables are complex, not clearly established, and are interwoven and difficult to measure.

2. Purpose:
In quantitative data, data is generalized, with prediction and casual explanation. In qualitative data, there is contextualization, interpretation, and understanding of perspectives.

3. Approach:
Quantitative research begins with hypotheses and theories. Experiments are conducted using instruments and deduction. Components are analyzed, data are reduced to indices and abstract language is used in conclusion. Qualitative research ends with hypotheses and theories. The researcher is the instrument and the reasoning is inductive. There is minor use of numerical indices and the write up is descriptive.

4. Role of the researcher:
The quantitative researcher is detached and impartial and is objective in carrying out the research. The qualitative researcher is partial and personally involved and has empathetic understanding.

Skill 1.8 Apply state statutes and national guidelines regarding laboratory safety, hazardous materials, experimentation, and the use of organisms in the classroom.

Safety in the science classroom and laboratory is of paramount importance to the science educator. The following is a general summary of the types of safety equipment that should be made available within a given school system as well as general locations where the protective equipment or devices should be maintained and used. Please note that this is only a partial list and that your school system should be reviewed for unique and site-specific hazards at each facility.

The key to maintaining a safe learning environment is through proactive training and regular in-service updates for all staff and students who utilize the science laboratory. Proactive training should include how to identify potential hazards, evaluate potential hazards, and how to prevent or respond to hazards. The following types of training should be considered:

> **a)** Right to Know (OSHA training on the importance and benefits of properly recognizing and safely working with hazardous materials) along with some basic chemical hygiene as well as how to read and understand material safety data sheets,
> **b)** instruction in how to use a fire extinguisher,
> **c)** instruction in how to use a chemical fume hood,
> **d)** general guidance in when and how to use personal protective equipment (e.g. safety glasses or gloves), and
> **e)** instruction in how to monitor activities for potential impacts on indoor air quality.

It is also important for the instructor to utilize **Material Data Safety Sheets**. Maintain a copy of the material safety data sheet for every item in your chemical inventory. This information will assist you in determining how to store and handle your materials by outlining the health and safety hazards posed by the substance. In most cases the manufacturer will provide recommendations with regard to protective equipment, ventilation and storage practices. This information should be your first guide when considering the use of a new material.

Frequent monitoring and in-service training on all equipment, materials, and procedures will help to ensure a safe and orderly laboratory environment. It will also provide everyone who uses the laboratory the safety fundamentals necessary to discern a safety hazard and to respond appropriately.

With appropriate planning and training, the maintenance of safe practices and procedures in areas of science instruction becomes integrated with the procedures for instruction and laboratory investigation. Safety procedures should be taught early and emphasized often to maintain a high level of safety awareness.

Safety Equipment

- Keep appropriate safety equipment on hand, including an emergency shower, eye-wash station, fume hood, fire blankets, and fire extinguisher. All students and teacher(s) should have and wear safety goggles and protective aprons when working in the lab.
- Ensure proper eye protection devices are worn by everyone engaged in supervising, observing, or conducting science activities involving potential hazards to the eye.
- Provide protective rubber or latex gloves for students when they dissect laboratory specimens.
- Use heat-safety items such as safety tongs, mittens, and aprons when handling either cold or hot materials.
- Use safety shields or screens whenever there is potential danger that an explosion or implosion might occur.
- Keep a bucket of 90 percent sand and 10 percent vermicullite or kitty litter (dried bentonite particles) in all rooms in which chemicals are handled or stored. The bucket must be properly labeled and have a lid that prevents other debris from contaminating the contents.

Teaching Procedures

- Set a good example when demonstrating experiments by modeling safety techniques such as wearing aprons and goggles.
- Help students develop a positive attitude toward safety. Students should not fear doing experiments or using reagents or equipment, but they should respect them as potential hazards.
- Always demonstrate procedures before allowing students to begin the activity. Look for possible hazards and alert students to potential dangers.
- Explain and post safety instructions each time you conduct an experiment.
- Maintain constant supervision of student activities. Never allow students to perform unauthorized experiments or conduct experiments in the laboratory alone.
- Protect all laboratory animals and ensure that they are treated humanely.
- Remind students that many plants have poisonous parts and should be handled with care.
- For safety, consider the National Science Teachers Association's recommendation to limit science classes to 24 or fewer students.

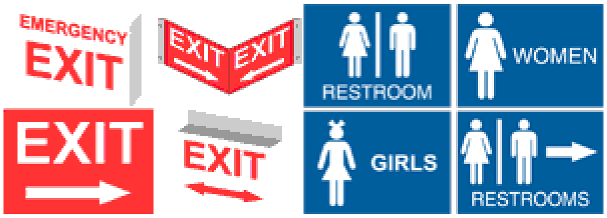
Student Safety Tips

- Read lab materials in advance. Note all cautions (written and oral).
- Never assume an experiment is safe just because it is in print.
- Do not eat or drink in the laboratory.
- Keep personal items off of the lab benches.
- Restrain long hair and loose clothing. Wear laboratory aprons when appropriate.
- Avoid all rough play and mischief in science classrooms or labs.
- Wear closed-toed shoes when conducting experiments.
- Never use mouth suction when filling pipettes with chemical reagents.
- Never force rubber stoppers into glass tubing.
- Avoid transferring chemicals to your face, hands, or other areas of exposed skin.
- Thoroughly clean all work surfaces and equipment after each use.
- Make certain all hot plates and burners are turned off before leaving the laboratory.

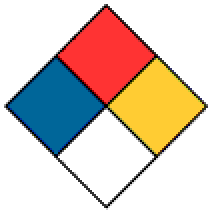
Lab Environment

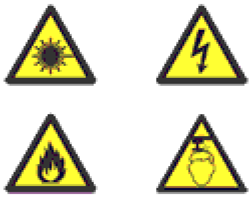
- Place smoke, carbon monoxide, and heat detectors in laboratories and storerooms.
- Ensure that all new laboratories have two unobstructed exits. Consider adding additional exits to rooms with only one door.
- Frequently inspect a laboratory's electrical, gas, and water systems.
- Install ground fault circuit interrupters (GFCI outlets) at all electrical outlets in science laboratories.
- Install a single central shut-off for gas, electricity, and water for all the laboratories in the school, especially if your school is in an earthquake zone.
- Maintain Material Safety Data Sheets (MSDS) on all school chemicals and an inventory of all science equipment.
- Conduct frequent laboratory inspections and an annual, verified safety check of each laboratory.

In addition to the safety laws set forth by the government for equipment necessary to the lab, OSHA (Occupational Safety and Health Administration) has helped to make environments safer by instituting signs that are bilingual. These signs use pictures rather than/in addition to words and feature eye-catching colors. Some of the best known examples are exit, restrooms, and handicap accessible.



Of particular importance to laboratories are diamond safety signs, prohibitive signs, and triangle danger signs. Each sign encloses a descriptive picture.





Skill 1.9 Differentiate between the various roles of communication in the development of scientific ideas (e.g., collaboration, peer review, scientific debate).

The development of scientific ideas relies upon communication among scientists. In addition to the use of the scientific method (hypothesis formation and subsequent testing), the acceptance of new scientific information requires that other members of the scientific world evaluate new ideas and findings. Often scientists will **collaborate** when working on new ideas. Input from several different scientists, especially if from different (but related) disciplines, can greatly enhance the development of new ideas. **Peer review** is another integral part of the development of scientific ideas. The peer review process means that before a scientific paper is published, it is scrutinized by independent qualified experts to ensure the validity and soundness of the ideas in the paper. This peer review process ensures that only high-quality research is published. **Scientific debate** refers to the process by which scientists argue about the validity of new hypotheses or ideas. Many new scientific ideas are at first subject to scrutiny, and are not always accepted. When scientists debate the validity of new claims, it helps ensure that only the strongest research and most robust ideas become accepted as fact.

Skill 1.10 Distinguish between accuracy, precision, systematic error, and random error, using significant figures appropriately.

Accuracy and Precision

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. A group of arrows that may or may not be near the bull's eye, but are near one another, represent precision.

Systematic and Random Error

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 acquire 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 that persists throughout the entire experiment, and are usually caused by an instrumental or human error.

Significant Figures

Significant figures or **significant digits** are the digits indicating the precision of a measurement. There is uncertainty in the last digit only.

Example: You measure an object with a ruler marked in millimeters. The reading on the ruler is found to be about 2/3 of the way between 12 and 13 mm. What value should be recorded for its length?

Solution: Recording 13 mm does not give all the information that you found. Recording 12 $\frac{2}{3}$ mm implies that an exact ratio was determined. Recording 12.666 mm gives more information than you found. A value of 12.7 mm or 12.6 mm should be recorded because there is uncertainty only in the last digit.

There are five rules for determining the **number of significant digits** in a quantity:

1) All nonzero digits are significant and all zeros between nonzero digits are significant.
   Example: 4.521 and 7002 both have four significant digits.
2) Zeros to the left of the first nonzero digit are not significant.
   Example: 0.0002 contains one significant digit.
3) Zeros to the right of a non-zero digit and the decimal point are significant.
   Example: 32.500 contains five significant figures.
4) The significance of numbers ending in zeros that are not to the right of the decimal point can be unclear, so this situation should be avoided by using scientific notation or a different decimal prefix. Sometimes a decimal point is used as a placeholder to indicate the units-digit is significant. A word like "thousand" or "million" may be used in informal contexts to indicate that the remaining digits are not significant.

   Example: 12000 m would be considered to have five significant digits by many scientists, but in the sentence, "The distance is between 11000 m and 12000 m," it almost certainly has only two. "12 thousand meters" only has two significant digits, but 12000.0 m has five, as indicated by the decimal point. The value should be represented as $1.2\text{x}10^4$ m (or $1.2000\text{x}10^4$ m). The best alternative would be to use 12 km or 12.000 km.

Exact numbers have no uncertainty and contain an infinite number of significant digits. These relationships are **definitions**. They are not measurements.

Example: There are exactly 1000 L in one cubic meter.

There are two rules for **rounding off significant digits**:

1) If the leftmost digit to be removed is a four or less, then round down. The last remaining digit stays as it was.

   Example: Round 43.4 g to two significant digits. Answer: 43 g.

2) If the leftmost digit to be removed is a five or more, then round up. The last remaining digit increases by one.

   Example: Round 6.772 g to two significant digits. Answer: 6.8 g.

Skill 1.11 Evaluate variables and affected outcomes for appropriate experimental designs with minimum bias.

Designing an experiment properly is critical because the success of the experiment depends on it. Before designing an experiment, one must identify the elements of an experiment.

1. **Control/standard**: A control is something the results of an experiment are compared against. Without this, we have no clue of the significance of the data obtained in an experiment.
2. **Constants**: An experiment needs to have multiple constants for better results. Many factors should be kept constant in an experiment. The reliability of the data/results depends to a greater extent on the number of constants. So, it is very important to identify all the possible constants in an experiment, which then make for a well-controlled experiment.
3. **Independent variables**: These are the variables we have the power to change. It is entirely at our discretion to choose the independent variables. These factors are going to influence the outcome of the experiment. One should remember that the number of independent variables must be limited to a maximum of four, otherwise the experiment gets complicated and the data may not be reliable.
4. **Dependent variable**: This is the factor that will be measured in an experiment. It is called dependent variable since its outcome is dependent on the independent variables.

After the experiment is conducted, it is of utmost importance to repeat the experiment at least twice to obtain reliable data, which will then be analyzed and conclusions drawn.

Inferring is a very important skill since it interprets the results and facilitates the researcher/scientist to draw logical conclusions.

Lastly, there is another important element to the experiment. The conclusions drawn must be communicated orally, and in written form for the benefit of furthering knowledge and sharing with the community to enlighten and educate it scientifically. This will help the society to become scientifically literate.

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.