

COMPETENCY 0001 UNDERSTAND COMMON THEMES AMONG THE SCIENCES AND THE RELATIONSHIPS THAT CONNECT MATHEMATICS, TECHNOLOGY, AND SCIENCE.**Skill 1.1 Similarities among systems in math, science, and technology.**

Math, science, and technology have common themes in how they are applied and understood. All three use **models**, **diagrams**, and **graphs** to simplify a concept for analysis and interpretation. **Patterns** observed in these systems lead to predictions based on these observations. Another common theme among these three systems is equilibrium. **Equilibrium** is a state in which forces are balanced, resulting in **stability**. Static equilibrium is stability due to a lack of changes and dynamic equilibrium is stability due to a balance between opposite forces. **Scale** is a ratio of size. For example, a map may have a scale of true miles per every inch drawn on the map. A model drawn to scale is a representation of something that is larger or smaller than its actual size. There is also the very literal interpretation of scale. In this context the scale would be used to measure mass, and would often be called a balance.

Skill 1.2 Apply concepts and theories from mathematics and other sciences to a biological system.

The knowledge and use of basic mathematical concepts and skills is a necessary aspect of scientific study. Science depends on data and the manipulation of data requires knowledge of mathematics. Understanding of basic statistics, graphs and charts, and algebra are of particular importance. Scientists must be able to understand and apply the statistical concepts of mean, median, mode, and range to sets of scientific data. In addition, scientists must be able to represent data graphically and interpret graphs and tables. Finally, scientists often use basic algebra to solve scientific problems and design experiments. For example, the substitution of variables is a common strategy in experiment design. Also, the ability to determine the equation of a curve is valuable in data manipulation, experimentation, and prediction.

Skill 1.3 Analyze the use of biology and other sciences in the design of a technological solution to a given problem.

Science and technology are interdependent as advances in technology often lead to new scientific discoveries and new scientific discoveries often lead to new technologies. Scientists use technology to enhance the study of nature and solve problems that nature presents. Technological design is the identification of a problem and the application of scientific knowledge to solve the problem.

While technology and technological design can provide solutions to problems faced by humans, technology must exist within nature and cannot contradict physical or biological principles. In addition, technological solutions are temporary and new technologies typically provide better solutions in the future. Monetary costs, available materials, time, and available tools also limit the scope of technological design and solutions. Finally, technological solutions have intended benefits and unexpected consequences. Scientists must attempt to predict the unintended consequences and minimize any negative impact on nature or society.

The problems and needs, ranging from very simple to highly complex, that technological design can solve are nearly limitless. Disposal of toxic waste, routing of rainwater, crop irrigation, and energy creation are but a few examples of real-world problems that scientists address or attempt to address with technology.

The technological design process has five basic steps:

1. Identify a problem
2. Propose designs and choose between alternative solutions
3. Implement the proposed solution
4. Evaluate the solution and its consequences
5. Report results

After the identification of a problem, the scientist must propose several designs and choose between the alternatives. Scientists often utilize simulations and models in evaluating possible solutions.

Implementation of the chosen solution involves the use of various tools depending on the problem, solution, and technology. Scientists may use both physical tools and objects and computer software.

After implementation of the solution, scientists evaluate the success or failure of the solution against pre-determined criteria. In evaluating the solution, scientists must consider the negative consequences as well as the planned benefits.

Finally, scientists must communicate results in different ways – orally, written, models, diagrams, and demonstrations.

Example:

Problem – toxic waste disposal

Chosen solution – genetically engineered microorganisms to digest waste

Implementation – use genetic engineering technology to create organism capable of converting waste to environmentally safe product

Evaluate – introduce organisms to waste site and measure formation of products and decrease in waste; also evaluate any unintended effects

Report – prepare a written report of results complete with diagrams and figures

Identify a design problem and propose possible solutions, considering such constraints as tools, materials, time, costs, and laws of nature.

In addition to finding viable solutions to design problems, scientists must consider such constraints as tools, materials, time, costs, and laws of nature. Effective implementation of a solution requires adequate tools and materials. Scientists cannot apply scientific knowledge without sufficient technology and appropriate materials (e.g. construction materials, software). Technological design solutions always have costs. Scientists must consider monetary costs, time costs, and the unintended effects of possible solutions. Types of unintended consequences of technological design solutions include adverse environmental impact and safety risks. Finally, technology cannot contradict the laws of nature. Technological design solutions must work within the framework of the natural world.

In evaluating and choosing between potential solutions to a design problem, scientists utilize modeling, simulation, and experimentation techniques. Small-scale modeling and simulation help test the effectiveness and unexpected consequences of proposed solutions while limiting the initial costs. Modeling and simulation may also reveal potential problems that scientists can address prior to full-scale implementation of the solution. Experimentation allows for evaluation of proposed solutions in a controlled environment where scientists can manipulate and test specific variables.

Skill 1.4 Use a variety of software and information technologies (e.g., spreadsheets, graphing utilities, statistical packages, simulations, on-line resources) to model and solve problems in mathematics, science, and technology.

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.

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Understand the historical and contemporary contexts of biological study and the applications of biology and biotechnology to everyday life.

SKILL 2.1 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 which gave 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 **transmission electron microscope (TEM)** was developed in the 1950s. Instead of light, a beam of electrons passes through the specimen. **Transmission** electron microscopes have a resolution about one thousand times greater than light microscopes. The disadvantage of the **TEM** is that the chemical and physical methods used to prepare the sample result in the death of the specimen.

In the late 1800s, Pasteur discovered the role of microorganisms in the cause of disease, pasteurization, and the rabies vaccine. Koch took this observations one step further by formulating that specific diseases were caused by specific pathogens. Koch's postulates are still used as guidelines in the field of microbiology: the same pathogen must be found in every diseased person, the pathogen must be isolated and grown in culture, the disease is induced in experimental animals from the culture, and the same pathogen must be isolated from the experimental animal.

DNA structure was another key event in biological study. In the 1950s, James Watson and Francis Crick discovered 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. Along with the pros of animal research, the cons are also very significant. 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.

Skill 2.2 Assess the societal implications of recent developments in biology and biotechnology

Society as a whole impacts biological research. The pressure from the majority of society has led to these bans and restrictions on human cloning research. Human cloning has been restricted in the United States and many other countries. 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.

Wastewater treatment is the process by which contaminants are removed from sewage. In addition to physical and chemical processing, biological methods are used to clean the wastewater and make it suitable for release back into the environment. Indigenous bacteria can be used to remove biological matter dissolved in the water. Activated sludge is the process in which sewage is aerated to allow the growth of various organisms, collectively known as biological floc, including saprophytic bacteria and protozoan. Advances in biotechnology have led to better management of activated sludge, allowing it to removed the bulk of organic material and the conversion of ammonia to nitrogen gas. These advances include moving bed biological reactors, biological aerated filters, and membrane biological reactors.

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 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 it is necessary that the public be scientifically literate and informed in order to stop potentially unethical procedures from occurring.** 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.

Competency 0003

Understand the process of scientific inquiry and the role of observation, experimentation, and communication in explaining natural phenomena.

Skill 3.1 Processes by which hypotheses are generated and tested

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 witchcraft, alien encounters or any topic that is explained by hearsay.

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 hypothesis theories, and laws.**

hypothesis - educated guess to best explain a phenomena. The hypothesis must be defined in such a way that it can be proved or disproved by experiments. Note the experiments must be repeated many times in order to prove the hypothesis.

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).

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 it is able to collect.** Data may be interpreted differently on different occasions. **The limitations of science cause explanations to be changeable as new technologies emerge.**

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 3.2 Analyze ethical issues related to the process of scientific research and reporting.

Scientists are expected to show good conduct in their scientific pursuits.

Conduct here refers to all aspects of scientific activity including experimentation, testing, education, data evaluation, data analysis, data storing, peer review, government funding, the staff, etc.

The following are some of the guiding principles of scientific ethics:

Scientific Honesty: not to fraud, fabricate or misinterpret data for personal gain

Caution: to avoid errors and sloppiness in all scientific experimentation

Credit: give credit where credit is due and not to copy

Responsibility: only to report reliable information to public and not to mislead in the name of science

Freedom: freedom to criticize old ideas, question new research, and freedom to research

Many more principles could be added to this list. Though these principles seem straightforward and clear it is very difficult to put them into practice since they could be interpreted in more ways than one. Nevertheless, it is not an excuse for scientists to overlook these guiding principles of scientific ethics.

To understand scientific ethics, we need to have a clear understanding of ethics. Ethics is defined as a system of public, general rules for guiding human conduct (Gert, 1988). The rules are general in that they are supposed to all people at all times and they are public in that they are not secret codes or practices.

Philosophers have given a number of moral theories to justify moral rules, which range from utilitarianism (a theory of ethics that prescribes the quantitative maximization of good consequences for a population. It is a form of consequentialism. This theory was proposed by Mozi, a Chinese philosopher who lived during BC 471-381), Kantianism (a theory proposed by Immanuel Kant, a German philosopher who lived during 1724-1804, which ascribes intrinsic value to rational beings and is the philosophical foundation of contemporary human rights) to social contract theory (a view of the ancient Greeks which states that the person's moral and or political obligations are dependent upon a contract or agreement between them to form society).

The common ethical code described above could be applied to many areas including science. When the general code is applied to a particular area of human life, it then becomes an institutional code. Hence, scientific ethics is an institutional code of conduct that reflects the chief concerns and goals of science. To discuss scientific ethics, we can look at natural phenomena like rain. Rain in the normal sense is extremely useful to us and it is absolutely important that there is water cycle. When rain gets polluted with acid, it becomes acid rain. Here lies the ethical issue of releasing all these pollutants into the atmosphere. Should the scientists communicate the whole truth about acid rain or withhold some information because it may alarm the public. There are many issues like this.

Whatever may be the case; scientists are expected to be honest and forthright with the public.

Skill 3.3 Evaluate the appropriateness of a specified experimental design to test a hypothesis.

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 **he** 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.

Skill 3.4 Analyze the use of models in explaining and investigating natural phenomena.

Once data has been collected and analyzed, it is useful to generalize the information by creating a model. A model is a conceptual representation of a phenomenon. Models are useful in that they clarify relationships, helping us to understand the phenomenon and make predictions about future outcomes. The natural sciences and social sciences employ modeling for this purpose.

Many scientific models are mathematical in nature and contain a set of variables linked by logical and quantitative relationships. These mathematical models may include functions, tables, formulas, graphs, and etc. Typically, such mathematical models include assumptions that restrict them to very specific situations. Often this means they can only provide an *approximate* description of what occurs in the natural world. These assumptions, however, prevent the model from **becoming** overly complicated. For a mathematical model to fully explain a natural or social phenomenon, it would have to contain many variables and could become too cumbersome to use. Accordingly, it is critical that assumptions be carefully chosen and thoroughly defined.

Certain models are abstract and simply contain sets of logical principles rather than relying on mathematics. These types of models are generally more vague and are more useful for discovering and understanding new ideas. Abstract models can also include actual physical models built to make concepts more

tangible. Abstract models, to an even greater extent than mathematical models, make assumptions and simplify actual phenomena.

Proper scientific models must be able to be tested and verified using experimental data. Often these experimental results are necessary to demonstrate the superiority of a model when two or more conflicting models seek to explain the same phenomenon. Computer simulations are increasingly used in both testing and developing mathematical and even abstract models. These types of simulations are especially useful in situations, such as ecology or manufacturing, where experiments are not feasible or variables are not fully under control.