## COMPETENCY 1.0 UNDERSTAND THE RELATIONSHIPS AND COMMON THEMES THAT CONNECT MATHEMATICS, SCIENCE, AND TECHNOLOGY.

### Skill 1.1 Analyzing similarities among systems in math, science, and technology (e.g., stability, equilibrium)

Math, science, and technology share many common themes. 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 opposing forces.

### Skill 1.2 Applying 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, 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 Analyzing 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 Using the Internet, a variety of software (e.g., spreadsheets, graphing utilities, statistical packages, simulations), and technologies (e.g., graphing calculators, computers) 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.

## COMPETENCY 2.0 UNDERSTAND THE HISTORICAL AND CONTEMPORARY CONTEXTS OF BIOLOGICAL STUDY AND THE APPLICATIONS OF BIOLOGY AND BIOTECHNOLOGY TO SOCIETY

### Skill 2.1 Recognizing the significance of key events in the history of biological study (e.g., development of the microscope, understanding the structure of DNA, use of animals in research, genomic research)

Anton van Leeuwenhoek is known as the father of microscopy. In the 1650s, Leeuwenhoek began making tiny lenses that produced magnifications up to 300x. He was the first to see and describe bacteria, yeast plants, and the microscopic life found in water. Over the years, light microscopes have advanced to produce greater clarity and magnification. The scanning electron microscope (SEM) was developed in the 1950s. Instead of light, a beam of electrons passes through the specimen. Scanning electron microscopes have a resolution about one thousand times greater than light microscopes. The disadvantage of the SEM is that the chemical and physical methods used to prepare the sample result in the death of the specimen.

In the late 1800s, Pasteur discovered the role of microorganisms in the cause of disease, pasteurization, and the rabies vaccine. Koch took this observation one step further by formulating a theory that specific pathogens caused specific diseases. Scientists still use **Koch's postulates** as guidelines in the field of microbiology. The guidelines state that the same pathogen must be found in every diseased person, the pathogen must be isolated and grown in culture, the pathogen must induce disease in experimental animals, and the same pathogen must be isolated from the experimental animal.

The discovery of the structure of DNA was another key event in biological study. In the 1950s, James Watson and Francis Crick identified the structure of a DNA molecule as that of a double helix. This structure made it possible to explain DNA's ability to replicate and to control the synthesis of proteins.

The use of animals in biological research has expedited many scientific discoveries. Animal research has allowed scientists to learn more about animal biological systems, including the circulatory and reproductive systems. One significant use of animals is for the testing of drugs, vaccines, and other products (such as perfumes and shampoos) before use or consumption by humans.
The debate about the ethical treatment of animals has been ongoing since the introduction of animals in research. Many people believe the use of animals in research is cruel and unnecessary. Animal use is federally and locally regulated. The purpose of the Institutional Animal Care and Use Committee (IACUC) is to oversee and evaluate all aspects of an institution's animal care and use program.

## Skill 2.2 Recognizing the contributions of diverse cultures and individuals to biological study

Curiosity is the heart of science. This is why so many diverse people are drawn to it. In the area of zoology one of the most recognized scientists is Jane Goodall. Goodall is known for her research with chimpanzees in Africa. She has spent many years abroad conducting long term studies of chimp interactions, and returns from Africa to lecture and provide information about Africa, the chimpanzees, and her institute located in Tanzania.

In the area of chemistry we recognize Dorothy Crowfoot Hodgkin. She studied at Oxford and won the Nobel Prize of Chemistry in 1964 for recognizing the shape of the vitamin B-12.

Florence Nightingale was a 19th century nurse who shaped the nursing profession. Nightingale was born into wealth and shocked her family by choosing to study health reforms for the poor in lieu of attending the expected social events. She studied nursing in Paris and became involved in the Crimean War. The British lacked supplies and the secretary of war asked for Nightingale's assistance. She earned her nickname walking the floors at night checking on patients and writing letters to British officials demanding supplies.

In 1903, the Nobel Prize in Physics was jointly awarded to three individuals: Marie Curie, Pierre Curie, and Becquerel. Marie Curie was the first woman ever to receive this prestigious award. In addition, she received the Nobel Prize in chemistry in 1911, making her the only person to receive two Nobel awards in science. Ironically, her cause of death in 1934 was of overexposure to radioactivity, the research for which she was so respected.

Neil Armstrong is an American icon. He will always be symbolically linked to our aeronautics program. An astronaut and naval aviator, he is best known for being the first human to set foot on the Moon.

Sir Alexander Fleming was a pharmacologist from Scotland who isolated the antibiotic penicillin from a fungus in 1928. Flemming also noted that bacteria developed resistance whenever too little penicillin was used or when it was used for too short a period, a key problem we still face today.

**Skill 2.3 Evaluating the impact of social factors on biological study (e.g., restrictions on the development of human cloning techniques, demand for genetically modified agricultural crops, bioethics)**

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

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

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

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

**Skill 2.4 Interpreting the implications for society of recent developments in biology and biotechnology (e.g., medical technology, genetic engineering, wastewater treatment, food safety)**

*Medical Technology*

The relationship between technology and society is synergistic. Applied research is of great value because it is directly useful to us; it deals with issues like AIDS, Tuberculosis, HPV, and Parkinson's disease. Technological advances have greatly increased the overall quality of medical care. Advances in medical technology that benefit society include the development of more advanced diagnostic and treatment tools and the expansion of medical research.

*Genetic Engineering*

Research in molecular genetics is highly technical and very useful to society. Because of it's use to humanity, molecular genetics receives generous funding from various sources and support from a large segment of the scientific community. Scientists use a number of techniques to isolate genes. The foremost technique is cDNA cloning, which is very reliable. The objective of these cloning experiments is to isolate many genes from a wide variety of living organisms. The applications of these isolated genes in genetic engineering are varied.

1. Using the clinically important genes for diagnostic purposes. The gene that encodes for one type of hemophilia has been used for this purpose. This field of research is proving to be of invaluable help to people suffering from various diseases like cancer and diabetes and research in this area holds a lot of promise for future generations.

2. Using the isolated genes to isolate similar genes from other organisms. Thus, isolated genes can serve as heterologous probes.

3. Using the isolated gene to derive the nucleic acid sequence. If a partial or complete sequence of the protein that it encodes is available, the gene can be confirmed in this manner. If the protein product is not known then comparing the sequence of the gene with those of the known genes can help derive a function for that gene. Knowing the function of a gene is very important in clinical diagnostic purposes.

4. Isolating a gene that causes disease in a particular crop will help farmers deal with that issue.

*Waste water treatment*

Wastewater treatment is the process that removes contaminants 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 remove 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.

*Food safety*

Food borne illness results from the consumption of food contaminated with pathogenic bacteria, viruses, parasites, or other biological toxins. The best preventative measure is proper controls and hygiene during food preparation. However, advances in biotechnology now mean that screening of food for toxins and pathogens can be done more easily. For instance, a fluorescent optical biosensor is currently being developed to measure antibiotic contaminants in milk. The biosensor measures reactions taking place on an antibody-coated probe in contact with the milk products. As testing becomes faster and cheaper, a larger percentage of the food we eat can be screened. Better biological testing methods may also help us identify pathogens that are currently unknown; the cause of approximately 60% of food borne illness is still not known.