Competency 1.0 Understand the relationship and common themes that connect mathematic, science and technology

Science, mathematics, and technology are interconnected. Teaching Chemistry incorporates the other sciences as well as other disciplines, such as mathematics. For example, graphs and charts are frequently used to record and analyze data. On a daily basis, we are surrounded with mathematics in the ability to make various measurements of mass and size, in the conversions betweens the numerous units, and in tabulating amounts of materials. Beyond these basic skills, mathematical and algebraic skills are used in a plethora of chemical calculations from determining the percent composition of elements in a compound to estimating the mass of reactants needed in a reaction.

The union of science, technology, and mathematics has shaped the world we live in today. Science describes the world. It attempts to explain all aspects of how nature works, from our own bodies to the tiny particles making up matter, from the entire earth to the universe beyond. Science lets us know in advance what will happen when a cell splits or when two chemicals react. Yet, science is ever-evolving. Throughout history, people have developed and validated many different ideas about the processes of the universe. Frequently, the development of new technology used in conducting experiments allows for new information and theories to emerge.

Chemistry is an everyday experience. Some facet of chemistry is involved in every aspect of our daily lives whether in the manufacture of the soaps and cosmetics one uses to get ready for the day, in the synthesis of the fabrics one wears, or in the production of the foods that are consumed daily.

Through the partnership of Chemistry and Biology, enormous advances in medicine and biotechnology have been made in the discovery of the molecular structure of the DNA molecule to the development of the field of medicinal chemistry. We have the ability to clone animals from a single adult cell and cure people of certain types of cancer. In the field of medicinal chemistry, scientists identify, synthesize, develop, and study chemicals to use for diagnostic tools and pharmaceuticals. Pharmacology is the study of how chemical substances interact with living systems. As biological knowledge has increased, the biochemical causes of many diseases have been determined and the field of pharmacology has grown tremendously. With the development of new medicines, antibiotics and vaccines, humans can be cured from common diseases and even avoid getting sick. Antibiotics are organic chemicals to kill or slow the growth of bacteria. Before antibiotics were available, infections were often treated with moderate levels of poisons like strychnine or arsenic. Antibiotics target the disease without harming the patient, and they have saved millions of lives. A baby born today in the United States is expected to live 30 years longer on average than a baby born 100 years ago. Since 1980, genetic engineering has been used to design recombinant DNA in order to produce human protein molecules in bioreactors using non-human cells. These molecules fight diseases by elevating the level of proteins made naturally by the human body or by providing proteins that are missing due to genetic disorders. Most tools in biotechnology originated from chemical technology, and with the continued partnership, better instruments and equipment will continue to be invented. With such developments, doctors can diagnose and treat patients more easily and with greater precision, so that we as a society are able to live longer and healthier lives.

In addition to a better quality of life we are able to increase the world's supply of food. Scientists have developed fertilizers, insecticides, and herbicides that enable us to grow stronger and healthier plants and to prevent diseases and pests in crops. The major breakthrough in the use of fertilizers from chemical processes occurred with the development of the Haber process for ammonia production in 1910:

$$N_2(g) + 3\ H_2(g) \leftrightarrows 2\ NH_3(g) \text{ over Fe catalyst}$$

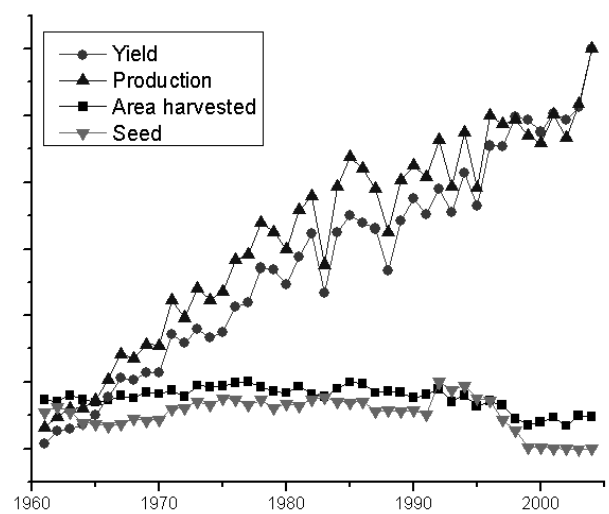
Millions of tons of ammonia are used worldwide each year to supply crops with nitrogen. Ammonia is either added to irrigation water or injected directly into the ground. Many other nitrogen fertilizers are synthesized from ammonia. Phosphorus in fertilizers originates from phosphate (PO_4^{3-}) in rock deposits. Potassium in fertilizers comes from evaporated ancient seabeds in the form of potassium oxide (K_2O). Pesticides are used to control or kill organisms that compete with humans for food, spread disease, or are considered a nuisance. Herbicides are pesticides that attack weeds; insecticides attack insects; fungicides attack molds and other fungus. Sulfur was used as a fungicide in ancient times. The development and use of new pesticides has exploded over the last 60 years, but these pesticides are often poisonous to humans. One example is the insecticide DDT. It was widely used in the 1940s and 1950s and is responsible for eradicating malaria from Europe and North America. It quickly became the most widely used pesticide in the world. In the 1960s, some claimed that DDT was preventing fish-eating birds from reproducing and that it was causing birth defects in humans. DDT is now banned in many countries, but it is still used in developing nations to prevent diseases carried by insects.

The herbicide *Roundup* kills all natural plants it encounters. It began to be used in the 1990s in combination with genetically engineered crops that include a gene intended to make the crop (and only the crop) resistant to the herbicide. This combination of chemical and genetic technology has been an economic success but it has raised many concerns about potential problems in the future.

Farming designed to maximize productivity is called intensive agriculture. These methods of fertilizer and pesticide use in combination with other farming techniques decreased the number of farm laborers needed and gave a growing world population enough to eat in the last 50 years. Intensification of agriculture in developing countries is known as the green revolution.

These techniques were credited with saving a billion people from starvation in India and Pakistan.

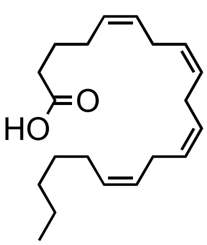
Total world production of coarse grain, 1961-2004



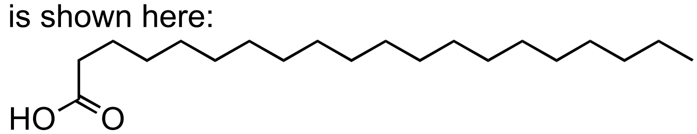
Source: Food and Agriculture Organization of the United Nations (http://faostat.fao.org/)

Technology makes use of scientific knowledge to solve real-world problems. For example, science is used to study the flow of electrons but technology is required to channel the flow of electrons to create a supercomputer. **Basic research** generally refers to investigation of fundamental scientific principles. **Applied research** is oriented toward making use of basic research in technology development. Applied research is dependent on basic research, and both are necessary for technology advancement. Mathematics in turn provides the language that allows this knowledge to be communicated. It allows the creation of models for scientists to use in explaining natural phenomena and is also the language of technology and computers.

Chemical technology helps keep foods fresh longer and alters the molecules in food. Processes such as pasteurization, drying, salting, and adding preservatives all prevent microbial contamination by altering the nutritional content of food. Preservatives are substances added to food to prevent the growth of microorganisms and spoilage. For example, potassium and sodium nitrites and nitrates are often used as a preservative for root vegetables and processed meats. Another method to preserve and sterilize food is by irradiation. Gamma rays from a sealed source of ^{60}Co or ^{137}Cs are used to kill microorganisms in over 40 countries. This process is less expensive than refrigeration, canning, or additives, and it does not make food radioactive.

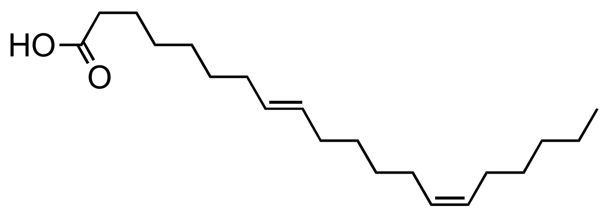


Another benefit of chemical technology is the ability to manipulate the chemical structure of molecules. Hydrogenation uses a chemical reaction to convert unsaturated to saturated oils. Many plant oils are polyunsaturated with double bonds in the ***cis-*** form as shown at left. These molecules contain rigid bends in them. Complete hydrogenation creates a flexible straight-chain molecule that permits more area for London dispersion forces to form intermolecular bonds. The result is that hydrogenation increases the melting point of an oil. Semi-solid fats are preferred for baking because the final product has the right texture in the mouth. Unfortunately, saturated fats are less healthy than *cis*- unsaturated fats because they promote obesity and heart disease. Complete hydrogenation of the molecule above is shown here:



When the hydrogenation process does not fully saturate, it results in partially hydrogenated oil. Partial hydrogenation often creates a semi-solid fat in cases where complete hydrogenation would create a fat that is fully solid.

However, partial hydrogenation of cis-polyunsaturated fats results in a random isomerization, creating a mixture of *cis*- and *trans*- forms. In the structure below, the molecule has been partially hydrogenated, resulting in the saturation of two double bonds. One of the two remaining *cis*- bonds has been isomerized to a *trans*- form:



Trans-fatty acids have a slight kink in them compared to *cis*- forms, and they rarely occur in the food found in nature. Campaigns against saturated fat in the 1980s led to the increased use of partially hydrogenated oils. The health benefits of monounsaturated fat were promoted, but labels made no distinction between *cis*- and *trans*- forms. As a result, there has been an increase in consumption of *trans* fat. Unfortunately, it is now known that *trans* fat is even worse for the body than saturated fat. Some nations have completely banned the use of partially hydrogenated oils. Food labels in the United States are currently (as of 2006) required to list total, saturated, and *trans*-fat content. Fatty acids with one or more *trans* nonconjugated double bonds are labeled as *trans* fat under this rule.

In the area of material science, we are able to improve our ability to synthesize materials and compounds. We have stronger and more durable fabrics that resist staining and daily wear better than the non-synthetic counterparts. Chemists have learned to synthesize plastics, which have a high strength-to-weight ratio. For example, a given piece of structural plastic can be up to six times stronger than steel with the same mass. We can even synthesize diamonds, which at one time were only available by tedious and dangerous mining.

With the increased amount of technology in the other fields of science, basic systems and modern conveniences are also being improved to benefit society. In our ever growing need for more power, Chemistry is playing a huge role in the area energy conservation and more efficient methods of producing energy.

Besides developing alternative fuel sources, like bio-diesel, we are producing better vehicles that are more efficient at combusting the petroleum fuel, and thus producing lower carbon dioxide emissions.

This technology has even produced hybrid and electric vehicles that operate on battery power and can convert the mechanical energy of braking into stored electrochemical power to recharge and run the car continuously.
Beyond our planet, technology has enabled us to travel to the moon and beyond. By analyzing the percent composition of the rocks and minerals found on the moon and Mars and comparing them to those on earth, scientists can begin to gather more information on whether life can exist on planets in our solar system.

The technological advances, which also include the computer, plasma TV, cell phones, CAT scan, and angioplasty to name a few, have become indispensable to human beings. The impact of chemicals and of the ability to alter matter by chemical technology has created tools that have improved the industrial production of nearly every substance. A basic understanding of all the multiple disciplines makes any society well informed and knowledgeable. Chemistry, physics, earth sciences, and biology are all closely involved with society, and many times we don't even notice it. Also, mathematics is interwoven into all of these fields to a great extent. By looking at the world around us closely we can visualize the interconnectedness of all the various disciplines.

The study of the properties and behavior of systems as a whole is known as **systems theory**. It is a highly interdisciplinary field ranging from physics to philosophy. **A system is composed of parts or activities that work together to form a whole**. The most basic definition of a system is a configuration of parts joined together by various relationships. Systems theory places emphasis on the recognition of the structure of systems and the dependence of its components on one another, even if in a time-delayed fashion. Typically, **the whole has unique properties not possessed by the parts alone.** As a result, systems theory prioritizes characterizing the behavior of the system and not the individual parts. This is occasionally at odds with the more traditional approach to science in which components are isolated as much as possible for study.

Systems theory encompasses physics, chemistry, biochemistry, biology, microbiology, engineering, economics, sociology, political science, management, psychotherapy, and many other disciplines. Therefore, systems-based models have been applied to a wide variety of instances in which multiple components interact. These systems can become quite complex. For instance, consider the human body. To understand how food is used to make energy, studying a single cell (cell biology) from the wall of the small intestine might give you some information about how free nutrients are absorbed, but you must also understand how all the organs in the digestive tract work together in sequence to digest the food (anatomy and physiology). Next, you would study the equally complex process by which energy in sugar is converted to ATP (adenosine triphosphate) using biochemistry. Again, simply examining the mechanisms of addition of a phosphate group to ADP (adenosine diphosphate) would not give you a full picture of what is happening. Only when relationships between components in the systems and the relationships between the systems are clear can the entire process be understood. This illustrates that components of systems may be separated by space and time and a single system may interact with other systems to form an even more complex system.

There are certain recurring themes and overarching “rules” that seem to govern science, technolgy, and mathematics. Those overarching “rules” are the **natural laws**: the laws of gravity, inertia, conservation of energy and mass, and the various ways in which matter naturallly behaves. Understanding chemistry is central to understanding these laws and, therefore, to understanding much of science, math and technology. Once one learns how to predict the physical and chemical properties of the elements, he can better predict the reactions of one element with another. Because reactions either need energy and emit energy, the study of chemistry leads to the study of energy transformations which borders on technology, and because those transformations conserve energy and mass, the mathematics must also be understood.

Certain themes recur throughout the sciences, technology and mathematics. The tendency of a system to achieve **equilibrium** is important whether we are observing chemical reactions or all the components in an ecosystem. The effect described by **chaos theory,** the creation of recognizable order from chaotic systems, has been observed throughout the sciences. In biology, understanding the forces of **evolution** is important whether considering a single biochemical pathway or an entire organism. Closely related is the recurring theme that the **structure** of biological subsystems is almost always a result of their **function**.