COMPETENCY 1.0 UNDERSTAND THE BASIC SCIENTIFIC PRINCIPLES OF EARTH AND SPACE SCIENCES.

Skill 1.1 Understand the role of energy in Earth systems.

Energy: the ability to do work (to cause change).

Work: the energy expended when the position or speed of an object is moved against an opposing force. Measured in Joules, work is the product of the force on an object and the distance through which the object is moved.

Forms of Energy

- Thermal Energy (heat): the energy of moving atoms and molecules.
- Chemical Energy: the energy that bonds atoms and molecules together.
- Nuclear Energy: the energy of moving the nucleus of an atom.
- Mechanical Energy: the energy of moving objects.
- Potential Energy: the energy stored in an object due to its position.
- Kinetic Energy: the energy an object has due to its mass and motion.

Energy is neither created nor destroyed. Any time something happens, energy is simply changing from one form to another.

Energy in the Earth Sciences

The movement of water in hydrologic processes releases energy that shapes the surrounding landforms. Magma chambers deep underground exert tremendous force and heat on the surrounding Earth materials, forcing changes in material composition, and often release energy through volcanic eruption or geothermal springs. Likewise, nuclear energy provides the motive force for generation of electricity, and solar radiation (energy) warms the planet. In each of these situations, a transfer (change of state) of the energy involved, is the primary motive force in the process. The energy released in each situation is dependent upon the mass and inherent energy of the substance.

Energy is the central driving force in Earth's systems and processes.

Skill 1.2 Understand the transfer and measurement of heat and the laws of thermodynamics as they relate to Earth systems.

Heat and Temperature

Heat: the total kinetic energy of the random motion of a substance's atoms and molecules.

Temperature: the measure of the average kinetic energy of the motion of atoms and molecules of a substance.

It is important to understand that there is a major difference between heat and temperature. Temperature is not a measure of how much heat a substance contains. Temperature is the increase or decrease of the kinetic energy of the atoms and molecules of a substance. Essentially, temperature is a measure of hotness, not heat. Although we use thermometers to measure temperature, we cannot directly measure heat; it must be calculated.

Temperature Measurement Units

Temperature is measured on three scales: degrees Fahrenheit (F), degrees Celsius (C), and Kelvin units (K). Note: Kelvin (K) is the measurement unit used in the System International (SI).

- Celsius Scale: the temperature scale in general scientific use.
- Fahrenheit Scale: the non-SI technical scale still used in some countries.
- Kelvin (K): the SI base unit of temperature, Kelvin is a unit on an absolute temperature scale. Note: There is no degree symbol ° written after a temperature expressed in Kelvin.

Absolute Zero is the point at which all motion ceases.

Heat Measurement Units

The primary heat measurement unit is Joules (J). However, heat is also commonly measured in Calories (cal). Yet another measurement scale is British Thermal Units (Btu).

Joule (J): the SI (System International) unit of measure for work and energy, the amount of work equal to the force of one Newton (1N) moving an object a distance of 1 meter (1 m).

Calorie (cal): the amount of heat energy required to change (raise or lower) the temperature of 1 gram of water by 1 degree Celsius.

British Thermal Unit (Btu): the amount of heat energy required to change (raise or lower) the temperature of 1 pound (lb) of water by 1 degree Fahrenheit. The Btu expresses heat unit in non-metric terms.

Equivalencies between heat measurement units

1 Joule (J) = 0.2389 cal = 9.48 X 10^{-4} Btu.
1 Calories (cal) = 4.184 J = 3.087 ft/lb.
1 British Thermal Unit (Btu) = 1054 J = 252.0 cal.

The Zeroth Law of Thermodynamics: If object A is in thermal equilibrium with object C, and object B is separately in thermal equilibrium with object C, then objects A and B will be in thermal equilibrium if they are placed in thermal contact. This law explains why objects of the same temperature do not spontaneously change temperature.

The First Law of Thermodynamics (The Law of Conservation of Energy): In a closed system, the total amount of energy always stays the same. It can change from one form to another, but the total amount of energy never changes. What this law states is that in a closed system—one that isn't affected by any outside influences—the total energy available can change between forms without any loss. However, the Earth is not a closed system. Although the base premise of the law still holds true, that total energy is conserved, the corollary to this law is: that any conversion of energy from one form to another results in some of the energy changing into heat.

The Second Law of Thermodynamics (Heat Flow): When objects of different temperatures are brought into thermal contact, the spontaneous flow of heat that results are always from the high temperature object to the low temperature object. Spontaneous heat flow never proceeds in the reverse direction. This law can be summed up as 'hot always goes to cold'. The convection currents that churn the semi-plastic molten material just below the Earth's crust illustrate the law's applicability to the Earth Sciences. Additionally, the rock material surrounding a magma chamber demonstrates the principle result of the law. The rocks heat up; the chamber does not cool as a result of contact with the rocks.

The Third Law of Thermodynamics: There is no temperature lower than absolute zero, and absolute zero is unattainable. The physics of this law is straight- forward. In order to lower the temperature of a substance, you must put it in contact with a colder substance. However, because nothing can physically be colder than absolute zero (the lowest limit), it is physically impossible to attain that temperature. You can approach absolute zero in finite steps (super cooling), but you will never actually reach the limit itself.

The Laws of Thermodynamics play a key role in most of the Earth's geologic processes.

Skill 1.3 Understand the structure of atoms and compounds, and their interrelationships in the solid, liquid, and gaseous components of Earth systems.

Atomic Structure

The atom is composed of Neutrons that have no charge and are therefore neutral, Protons that are particles with a positive charge, and Electrons that have a negative charge. Because each electron is equal in strength to the positive charge of a proton, when the number of electrons equals the number of protons, the atom is considered neutral. The nucleus of the atom is composed of nucleons, which when electrically charged are protons and when electrically neutral are neutrons. The electrons swirl around the nucleus in a large region called the Electron Cloud.

The Sizes and Masses of Atoms

Atoms are almost inconceivably small. Atoms are so tiny that it would take about 1×10^{18} atoms to make up the punctuation mark at the end of this sentence. Likewise, the nucleus of the atom makes up only a small part of the total size of the atom. Strangely enough, although physically a very small part of the atom, almost all of the atom's mass is located in the nucleus. The nucleons are 2000 times the mass of electrons, and this mass is represented by a mass number, which is equal to the sum of the masses of the protons and neutrons, each of which have about the same mass—one atomic mass unit (amu). Electrons, despite taking up the most space, contribute very little to the mass of the atom; in fact their actual mass is so small that the atomic mass unit of an electron is considered to be zero. An element's atomic number is a number representing the number of protons in an atom's nucleus. If combined with its Mass Number, the sum of the masses of the protons and neutrons in an atom can be combined to easily calculate the number of electrons, protons, and neutrons in a stable, neutral atom of that element.

Isotopes: atoms that have like numbers of protons, but unlike numbers of neutrons. Most elements have two to ten stable isotopes, each of which may cause a modification of the element's physical properties.

The electron is the mobile part of the atom, arranged in a special pattern called the Electron Configuration, which is unique to each element. The electron cloud that surrounds the atom is divided into energy levels, each of which can only hold a maximum number of electrons. The farther the electrons are from the nucleus, the more energy they have.

Electrons can move between levels if they have enough energy. The closest level to the nucleus can only hold two electrons, the second energy level can hold a maximum of eight electrons, while the third energy level can hold up to eighteen electrons.

The key factor in combining elements into a **Compound**: a pure substance composed of elements that have been chemically combined, lies in the fact that electrons can move from one atom to another. A neutral atom has the same number of protons as electrons, but if you take one or more electrons away, the atom is left with extra protons and becomes positively charged. Conversely, the atom that gains the electrons becomes negatively charged. Negatively charged atoms are called **Ion**s: an atom or a group of atoms that has an electrical charge because it has gained one or more electrons. The attractive forces between ions and positively charged atoms can cause dissimilar atoms to combine, forming a new substance.

In the Earth Sciences, the atomic structure of the elements and how they combine to form new substances are of critical importance. Either combining or dissolving energy bonds, both electrical and chemical, forms most minerals. Solar radiation directly affects our upper atmosphere, stripping oxygen molecules off of ordinary Oxygen (O_2), and resulting in Ozone (O_3) that protects us from harmful ultra-violet (UV) radiation.

Skill 1.4 Understand nuclear reactions and their products as they relate to the Earth and Space Sciences.

The Basics of Nuclear Reactions

The basic principle behind a nuclear reaction is actually quite simple. In the process of **Fission**- splitting an atom- if you bombard the nucleus of an atom with a neutron, you cause the nucleus to split into two nuclei. The reactive process repeats itself over and over, releasing yet more energy and neutrons. This process is called a **Chain Reaction**: a process in which an action causes a reaction that causes subsequent cycles of action and reaction.

Based upon Albert Einstein's famous equation of $E=mc^2$, the energy released during fission is directly proportional to the mass of the substance times the speed of light squared. This equation simply illustrates the tremendous amount of energy available for release by a fission reaction. Considering that the speed of light is 299792458×10^8 m/s, if you square that number you end up with a tremendously large number, and then multiply that by the mass of the substance split, you can see that, mathematically, the exponential release of energy is huge.

Nuclear Power

Our world is energy dependent, and the primary purpose of nuclear reactors is to supply that energy. Fortunately, we can control the fission process by limiting the number of neutrons available for reactions. Control rods of boron, graphite, and cadmium are inserted between the radioactive fuel rods in a nuclear reactor. These control rods absorb neutrons, and are designed to limit the number of neutrons to one per fission reaction. The inherent potential weakness of a nuclear reactor is safely controlling the reaction. The mechanisms that insert and remove and the control rods must function correctly on demand. The continued circulation of water to remove excess heat is absolutely critical to the safe operation of the reactor. Likewise, ensuring that radioactive steam from the primary system isn't vented into the atmosphere is another safety concern. A breeder reactor creates more fissionable fuel than it consumes. Unfortunately, plutonium, while useful as a nuclear fuel, has an extremely long half-life and is known to be one of the most toxic substances to living organisms. Unlike radioactive elements such as uranium, which damage cellular structure causing cancer, plutonium kills cells outright. Another major problem is disposing of the plutonium fueled breeder reactors' wastes, as plutonium takes hundreds of thousands of years to decay.

Nuclear Energy Issues

The continued use of nuclear reactors to generate power is a major source of contention. On the one hand, our technologically and energy dependent civilization demands ever increasing amounts of energy in the face of an ever shrinking fossil fuel supply, and admittedly, if operated correctly, nuclear power plants do not pollute the air or the water supply. On the other hand, nuclear reactors potentially endanger our lives through accidental release of radioactivity to the air or groundwater, proliferation of weapons grade nuclear material, and safe disposal of radioactive and toxic byproducts. Burying the radioactive wastes is an expensive and short-term solution. It also is becoming problematic to find suitable locations. The ground swell of public opinion against burial can be summed up by the acronym NIMBY- not in my backyard. The power supplied is nice, but few people welcome a radioactive waste disposal site in close proximity to their homes. We are running out of places to store the approximately 200 tons of radioactive waste produced daily in the United States. Most of the waste is being buried deep underground, especially in the barren desert regions bordering the mountains of the southwestern states. Other waste is being encased in concrete and lead containers and dumped in the deeper parts of the oceans. Each of these solutions presents technological difficulties and hazards.

Skill 1.5 Understand fundamental biological, chemical, and physical processes as they apply to the study of Earth and Space Sciences.

Characteristics of Living Matter

- It must be able to reproduce new individuals.
- It must also be capable of growing by using nutrients and energy from its surroundings.
- It responds in some manner to outside stimuli.
- It must show chemical uniformity.

Cellular Structure

The cell is the fundamental structure of living organisms. Cells come in two basic types, **Prokaryotic Cells**: cells that have no membrane, and **Eukaryotic Cells**: cells that have a nucleus containing hereditary information and surrounded by a membrane. Animal and plant cells are eukaryotic. Cells differ in both size and shape. A single nerve cell may be a meter long, while a human egg cell is no larger than the period at the end of this sentence. Additionally, the cell's shape is often an indicator of the function the cell performs.

DNA (Deoxyribonucleic Acid) is a long, twisted molecule composed of four different types of sugar and phosphate compounds linked together with nitrogen-bearing bases. The genetic information for reproduction of the cell is driven by the order in which the bases are arranged. **RNA** (Ribonucleic acid) is responsible for the production of organic molecules in living organisms. RNA is a shorter, single-stranded linear molecule. Amino Acids are small, nitrogen-bearing molecules that form Proteins. Proteins consist of many amino acids linked in a specific order into chains, and then folded into a complex shape that governs the protein's function. All living organisms contain both DNA and RNA and share a common genetic code by which proteins are made.

Reproduction

When an organism reproduces, it does so in two ways:

- Somatic: The process of Mitosis: cell division. Cells divide, resulting in two identical cells.
- Gametes: The process of Meiosis: a recombination of chromosomes and genes that produce a different cell. The genetic recombination process starts when eggs and sperm combine. Genes start with four chromosomes. Due to meiosis, the chromosomes are split off as single chromosomes.

In asexual reproduction, no eggs or sperm are involved. This is simple cellular duplication.

Biological Classification

Taxonomy: a way of classifying life that relates organisms to each other. All living organisms are grouped within five kingdoms:

Five Kingdoms

- Monera = Bacteria.
- Protista = Unicellular non-bacteria.
- Plants
- Fungi
- Animals

Evolution

Organic Evolution: the idea that all life on earth is descended from other life, and that all life is linked through a process of ancestry and descent. The branching of life causes an increase in complexity as evolution progresses. Organisms evolved from simple to more complex forms.

Population: a group of animal organisms that are capable of natural breeding.

The slow change in a population over time is the result of genetic mutations, gene recombination, and natural selection. In estimating the viability of a population, you must take into account the geographic boundaries. Genetic recombination is critical to the survival of the organism.

How Evolution Proceeds

The key to understanding how evolution proceeds is to look at the fossil records. There are two ways of proceeding:

- **Phyletic Gradualism**: the organism changes as the environment changes. This path is based on a slow, gradual, uniform change.
- **Punctuated Equilibrium**: there are little changes in organisms, and they are one-time developments punctuated (ended) by short time periods of rapid evolutionary change.

The Chemistry of Matter

There are two principal ways of classifying matter: by its physical state or by its chemical constitution as an element, compound, or mixture.

States of Matter

- **Solid**: the form of matter characterized by rigidity. A solid has a fixed shape and volume.
- **Liquid**: the form of matter that is relatively incompressible fluid. A liquid has a fixed volume, but no fixed shape.
- **Gas**: the form of matter that is an easily compressible fluid. A given quantity of gas will fit into a container of almost any size and shape.
- **Plasma**: the special form of matter that is created from superheated, molten gas.

Reaction and Change

Physical Change: a change in the form of matter but not in its chemical identity. The matter can be separated back into individual, original identities.

Chemical Change (Chemical Reaction): a change in which one or more kinds of matter are transformed into a new kind of matter, or several new kinds of matter.

We characterize or identify a material by its various properties, which may be either physical or chemical.

- **Physical Property**: a characteristic that can be observed for a material without changing its chemical identity.
- **Chemical Property**: a characteristic of a material involving its chemical change.

Chemical Compositions

Substance: a kind of matter that cannot be separated into other kinds of matter by any physical process.

Elements, Compounds, and Mixtures

Element: a substance that cannot be decomposed by any chemical reaction into simpler substances. In chemical reactions elements form compounds.

Compound: a substance composed of two or more elements chemically combined.

Mixture: a material that can be separated by physical means into two or more substances. Most materials around us are mixtures and a mixture has a variable composition.

Mixtures are classified into two types.

- **Heterogeneous Mixture**: a mixture that consists of physically distinct parts, each with different properties.
- **Homogeneous Mixture** (Solution): a mixture that is uniform in its properties throughout a given sample.

The Periodic Table of Elements

Periodic Table of Elements: a tabular arrangement of elements in rows and columns, highlighting the regular repetition of properties of the elements. The basic arrangement of rows and columns actually represents periods and groups.

- **Period**: the elements in any one horizontal row of the periodic table.
- **Group**: the elements in any one column of the periodic table.

Bonding and Chemical Formulas

Bonding: the forces that hold atoms together.

Ionic Bonding: chemical bonds formed by the electrostatic attraction between positive and negative ions. Ionic bonding relies on the exchange of **Ions**: an electrically charged particle obtained from an atom or chemically bonded group of atoms by adding or removing electrons. The electrons are transferred from the valence shell (outer shell) to the other atom's valence shell.

Covalent Bonding: when two atoms share valence electrons (outer shell electrons), which are attracted to the positively charged cores of both atoms.

Molecule: a definite group of atoms that are chemically bonded together. Strong attractive forces accomplish this tight bond.