The Structure and Function of Biological Membranes

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Overview

Biological membranes are among the fundamental concepts upon which cellular biology is based. Regardless of their nature, prokaryotic or eukaryotic, membranes are integral to the structure and function of all cells. Among their roles, membranes are essential to: maintaining the integrity of the cell and the various membrane-bound organelles within the cell, regulating the transport of materials into and out of the cell, responding to external and internal stimuli, and cell-to-cell recognition. Due to the functional complexity of biological membranes, it was necessary to narrow the scope of this unit to the chemistry of membrane structure and the transport of substances across membranes. The behavioral objectives for this unit are twofold. They include the ability of the students to: compare and contrast the chemical composition of biological membranes from a variety of prokaryotic and eukaryotic cells. In addition, the students will examine the mechanisms by which materials are transported across membranes. This curriculum unit is designed to be a recurrent theme throughout the academic year rather than restricted to a limited timeframe. Material from this unit will be incorporated in the following units from the Planning and Scheduling Timeline for Chemistry, Unit 1: Matter and Energy, Unit 4: Ionic Bonds and Nomenclature, Unit 5: Covalent Bonds and Nomenclature, Unit 9: Intermolecular Forces, and Unit 11: Equilibrium and Chemical Kinetics (1). Even though this unit was developed for implementation in a chemistry classroom, it can very easily be adapted for use in a biology classroom.

Rationale

This curriculum unit is designed to focus on two major aspects of biological membranes. Initially, the structure and composition of biological membranes will be examined with an emphasis being placed on the similarities as well as differences among membranes from various sources. The second main area of concentration deals with the function of membranes. In this section, particular attention will center on the different transport mechanisms across cell membranes. Information presented in the rationale section of this unit was obtained from a variety of sources including: Molecular Biology of the Cell (2), Biology (3), Life: The Science Of Biology (4), and a number of internet articles (5, 6, 7, 8, 9, 10, 11, 12, 13, 14, and 15).

Structure and Composition of Biological Membranes

Depending on the cell type, function, and species, the thickness of biological membranes will vary from approximately 2 to 10 nanometers. Regardless of their source, all biological membranes have a number of structural characteristics in common. The main feature of all membranes is their phospholipid bilayer organization. Phospholipids are unique molecules in that one end of the molecule is polar or hydrophilic with the other end being nonpolar or hydrophobic. This type of molecule is referred to as amphiphilic that is having both hydrophilic and hydrophobic regions. The nonpolar end of the lipid is composed of two fatty acids chemically bond to either a glycerol or serine molecule. The fatty acids generally range from fourteen to twenty-four carbon atoms in length. One of the fatty acids is saturated whereas the other one is unsaturated with at least one *cis*-double bond. Furthermore, chemically bound to the glycerol or serine portion of the molecule is a single phosphate group to which the polar end of the phospholipid is attached. These polar ends can be ethanolamine, choline, serine, or to a lesser extent inositol. Four very common phospholipids found in membranes include: phosphatidylcholine, phosphatidylserine, phosphatidylethanolamine, and sphingomyelin. The later phospholipid is the only one mentioned in which the fatty acids are chemically bound to a serine molecule rather than glycerol. The molecules are aligned in such a manner that the inner part of the membrane is composed of the hydrophobic ends of each fatty acid while the hydrophilic portion of each molecule either faces the exterior or interior portions of the cell. It should be noted that the arrangement of the phospholipids within the bilayer structure is not uniform. This asymmetric organization is due to differences in the chemical compositions of the inner and outer monolayer portions of the phospholipid bilayer. In addition to phospholipids, the membrane bilayer may also contain glycolipids, proteins, as well as cholesterol.

Since the molecules within the lipid bilayer are not physically attached to each other a certain degree of movement takes place within the membrane. Lateral diffusion within each monolayer occurs when membrane phospholipids exchange places. In addition, these molecules are free to rotate about their axis. Movement of their hydrophobic ends likewise takes place. This fluidity within the membrane is greatly dependent upon the composition of each monolayer. The hydrocarbon chain length and the number of *cis*-double bonds within specific fatty acids both appear to influence the degree of fluidity within the membrane. The shorter the fatty acid length and the more double bonds within the fatty acid favor an increased fluidity within the membrane. Not only is cholesterol a major component of eukaryotic plasma membranes, but it also has a profound effect on the fluidity of the membrane. It is estimated that in eukaryotic cells the ratio of phospholipid to cholesterol molecules is on the order of one to two. Each amphiphilic cholesterol molecule has the same membrane orientation as the phospholipids. Its steroid ring structure inhibits the movement of adjacent phospholipids thereby decreasing both fluidity and membrane permeability.

Proteins are integral components in the composition of membranes. For example, seventy-six percent of the inner mitochondrial membrane is protein and twenty-four percent is phospholipid. The plasma membranes from human red blood cell, in comparison, contain forty-four percent proteins and forty-three percent phospholipids. The myelin from nerve fibers only contains about eighteen percent proteins with seventy-six percent being phospholipids. These membrane proteins participate in a number of fundamental roles including: receptors, enzymes, and as transport proteins. The two basic types of membrane proteins are integral and peripheral proteins. The integral proteins are those proteins which are tightly bound to the membrane whereas the peripheral proteins are loosely bound to only one side of the lipid bilayer. The manner in which a protein is associated with the membrane is indicative of its role. Transmembrane proteins are integral membrane proteins since they traverse the membrane from one side to the other.

Biological Membranes and the Transport of Molecules

One the integral roles attributed to membranes is the regulation of materials into and out of the cell and/or membrane-bound organelles. Due to the amphiphilic nature of the phospholipids, the ability to traverse a membrane is a function of both the size and polarity of the molecule. Whereas very small nonpolar molecules are able to diffuse fairly rapidly across membranes, polar molecules experience a certain degree of difficulty. Uncharged polar molecules less than ninety daltons in size are capable of diffusing across membranes, whereas those greater than ninety daltons in size do not. One dalton is equivalent to 1.66×10^{-24} grams. Ions, however, are incapable of diffusing across the membrane regardless of their size. From this it is apparent that the movement of substances across biological membranes involves a number of different mechanisms. The major cellular transport mechanisms are passive transport and active transport.

Passive Transport

The process whereby substances move from one side of a membrane to the other without the expenditure of energy is referred to as passive transport or diffusion. In this type of transport, the movement of an uncharged substance across the membrane is based solely on differences in concentration. This concentration gradient determines the direction of transport which is from an area of greater concentration to one of lesser concentration. The energy needed to drive this reaction is in accordance with Gibb’s free energy as shown in equation 1:

$\Delta G = RT\ 2.303\ \log_{10}[X]_{out} / [X]_{in}$ (equation 1)

where ΔG is the change in free energy, R is 1.99 cal/ mol degree Kelvin, T is the temperature in Kelvin, $[X]_{out}$ and $[X]_{in}$ represent the concentrations of the substance on either side of the membrane. The direction of transport will favor a negative ΔG value.

The rate of diffusion, however, can be determined by employing Fick's law of diffusion according to equation 2:

$J = -DA\ (C_{out} - C_{in}) / L$ (equation 2)

In the above equation, J is the diffusion rate, D is the diffusion coefficient, A is the cross sectional area of the membrane, C_{out} and C_{in} represent the concentration of the substance outside and inside the membrane respectively, and L is the thickness of the membrane. Dividing the product of the diffusion coefficient and the cross sectional area by the thickness of the membrane the permeability coefficient (P) can be determined. Using the permeability coefficient in the preceding equation, will yield equation 3:

$J = -P\ (C_{out} - C_{in})$ (equation 3)

Simple diffusion differs from facilitated diffusion in that a carrier protein is required in facilitated diffusion. As was stated earlier, in addition to the phospholipids, proteins are important to the structural composition of membranes. Not only are there are a number of different functions attributed to membrane proteins, but there are also a number of different ways in which these proteins are associated with the membrane. Transmembrane proteins, whether single pass or multiple pass, span the membrane with portions of the protein on either side of the membrane. It is believed that one role of these transmembrane proteins is to mediate the transport of substances across the membrane. They can act either as carrier proteins or as channel proteins. A carrier protein functions by binding to a specific uncharged substance and then by undergoing a number of structural changes is able to transport that molecule across the membrane. Channel proteins form a channel through which polar molecules and/or ions can pass from one side of the membrane to the other. A discrete set of channel proteins, the ion channel proteins, form channels or pores through which ions of a specific size and charge can pass. It has been estimated that the rate of transport through these ion channels is on the order of one thousand times greater than the rate of transfer by way of any other type of carrier protein. To regulate the flow of ions through the ion channel protein, these transmembrane proteins have the ability to open or close the pore through which the ion is transported. These are referred to as voltage-gated channels.

The difference in the concentration of ions on either side of a membrane creates an electrochemical gradient or membrane potential. In general, the interior of a cell tends to have an overall negative charge with respect to its exterior environment. This potential difference favors the transport of positively charged substances into the cell. Therefore, the transport of charged molecules and/or ions across a membrane is not only based on concentration differences, but it is also based on its membrane potential. Equation 4 is applicable for determining the change in free energy for the transport of ions:

$\Delta G = zFV_m$ (equation4)

where z is the valence or ionic charge, F is the Faraday constant or 2.3×10^4 cal/mol V, and V_m is the membrane potential in millivolts. By combining equations 1 and 4, equation 5 can be derived which combines both concentration and electrochemical gradients.

$\Delta G = RT\ 2.303 \log_{10} [X]_{out} / [X]_{in} + zFV_m$ (equation 5)

Therefore at equilibrium and 298 K where ΔG is zero, the previous equation can be rewritten as equation 6:

$V = (60 / z) \log_{10} [X]_{out} / [X]_{in}$ (equation 6)

Equation 6, known as the Nernst equation, is useful in determining the membrane potential for a particular cell.

Active Transport

The transport of substances against a concentration gradient is known as active transport and requires both a carrier protein and an energy source. These transmembrane carrier proteins have been classified as uniport, symport, and antiport carrier proteins. The uniport carriers transport a single molecule from one side of the membrane to the other. Both symport and antiport carrier proteins involve the dependent transfer of two molecules and as such they are also referred to as co-transporters. Symport carriers transport two molecules in the same direction, such as amino acids and Na^+. Antiport carriers, in comparison, transport the two molecules in opposite directions, as in the case of Na^+ and K^+. The transport of macromolecules such as proteins and polysaccharides rely on vesicular transport. In this type of transport, membranous vesicles are formed around the substance or substances that are to be transported into or out of the cell or membrane bound organelle. Where endocytosis refers to vesicular transport into the cell, exocytosis is the vesicular transport of substances out of the cell. Two forms of endocytosis are: pinocytosis, and phagocytosis. The two are classified on the basis of the size of the transport vesicles. Pinocytosis involves vesicles up to 150 nm in diameter whereas in phagocytosis the vesicles formed are in excess of 250 nm in diameter.

The energy required for the active transport of molecules across a membrane can come from the hydrolysis of adenosine triphosphate (ATP) or from specific ion gradients. Active transport can be classified into primary or secondary active transport. The energy released from the hydrolysis of ATP drives the primary active transport mechanism, whereas ion gradients drive the secondary active transport mechanisms. There are several different classes of primary active transport which include: P-class ion pumps, F-class ion pumps, V-class ion pumps, and the ATP-binding cassette or ABC superfamily. Included in the P-class are the Na^+ - K^+ ATPase, Ca^{2+} ATPase, and the H^+- K^+ ATPase pumps. Although the F-class and V-class pumps are believed to transport only H^+, they are both more complex than the P-class pumps. Within the ABC superfamily there are approximately one hundred known transport proteins. All of these proteins share a number of similar characteristics. The ABC superfamily is responsible for the transport of a variety of substances ranging from simple inorganic ions up to and including some proteins.

As stated earlier, secondary active transport does not involve the energy released from the hydrolysis of ATP. Instead, it involves the transport of a substance against its concentration gradient with the concomitant transport of an ion along its electrochemical gradient. Secondary active transport may include either symport or antiport co-transporters and are responsible for the transport of such substances as amino acids and sugars. An example of secondary active transport involving a symport co-transporter is glucose and Na^+. As the direct result of the Na^+ - K^+ ATPase pump, the diffusion of Na^+ into the cell along its electrochemical gradient provides the energy necessary for the transport of glucose into the cell against its concentration gradient. The transport of Na^+ into the cell and Ca^{2+} out of the cell is an example of secondary active transport involving an antiport co-transporter. Once again the energy needed to drive the reaction was obtained from the equilibrium established as a result of the Na^+ - K^+ ATPase pump.

Objectives

This curriculum unit was developed with the specific intent of teaching tenth grade chemistry students the fundamental chemical concepts associated with the structure and function of biological membranes. It will be a recurrent theme throughout the academic year being integrated into a number of units within the School District of Philadelphia's standardized curriculum for chemistry. It is envisioned that the resources and activities utilized throughout the unit will: demonstrate a direct correlation between the physical and life sciences, help stimulate creative thought, and encourage students to appreciate the many aspects of chemistry. The activities used throughout the unit were designed to teach a variety of standards and concepts presented throughout the academic year. These standards and concepts are in direct alignment with both the Pennsylvania Academic Standards for Science and Technology and the School District of Philadelphia's core curriculum for chemistry.

As designed, the curriculum unit is intended to target a number of Pennsylvania Academic Standards for Science and Technology. They include, but are not limited to, the following standards: 3.1.10 D "Unifying Themes – apply scale as a way of relating concepts and ideas to one another by some measure", 3.1.10 E "Unifying Themes - describe patterns of change in nature, physical and man made systems", 3.4.10 A "Physical Science, Chemistry, and Physics - apply concepts about the structure and properties of matter", 3.4.10 B "Physical Science, Chemistry, and Physics - apply and analyze energy sources and conversions and their relationship to heat and temperature", 3.4.10 C "Physical Science, Chemistry, and Physics - distinguish among the principles of force and motion", 3.7.10 A "Technological Devices – apply advanced tools, materials, and techniques to answer complex questions", 3.7.10 B " Technological Devices – evaluate appropriate instruments and apparatus to accurately measure materials and processes", and 3.8.10 C "Science, Technology and Human Endeavors – evaluate possible consequences and impacts of scientific and technological solutions" (16).

Strategies

Several years ago, in an ongoing effort to improve student achievement throughout the district, the School District of Philadelphia adopted an initiative for all high schools. The six step plan includes the following teaching strategies. In the first strategy, students are expected to preview content specific vocabulary on a daily basis. They are also expected to be able to preview, analyze, and connect material presented in textbooks. The remaining strategies include: reciprocal teaching, the ability to summarize material, the use of comprehension connectors or graphic organizers, and the ability to take notes. Since this curriculum unit is anticipated to be an ongoing project throughout the academic year, most if not all of the aforementioned strategies will be used.

Parts of this unit will also necessitate the use of cooperative learning strategies which has been a successful pedagogical strategy for many years. The benefits of which have been shown to increase scholastic achievement, improve social skills, as well as team self-esteem. In order for cooperative learning to be an effective teaching strategy, deliberate care must be used in evaluating its ideal classroom design. There are six basic factors that one needs to consider in establishing and maintaining an effective cooperative learning environment. These factors include: team organization, cooperative management, the will to cooperate, the skill to cooperate, basic practices, and structuring the cooperative lesson. A synopsis of each will be presented in the presented in the following paragraphs (17).

From past experiences, team organization tends to be most effective when there is academic heterogeneity among the students rather than random selection. Academic heterogeneity allows for the establishment of teams or groups each of which contains students with high, average, and below average scholastic ability. Administering an entrance test the first week of school is extremely useful in this regard. Groups consisting of no more than four students have been ideal for a variety of reasons. Lateness and absences are real concerns for most of the high schools within the School District of Philadelphia. With four students in a group, individual groups can still function even when half of the students in any one group are absent. From the standpoint of classroom management, teacher determined learning groups tend to eliminate or diminish behavioral problems associated with those groups which were determined by the students.

Classroom management is essential to an effective cooperative learning environment. This can be accomplished through: cooperative management, the will to cooperate, and the skill to cooperate. It is imperative that students understand the guidelines for acceptable classroom behavior. For example, teachers must establish consistency in dealing with unacceptable noise level within the classroom. The will to cooperate is developed over time and is based on positive social interactions and pride within the group. The skill to cooperate is based on the ability of the students to assume specific roles within the group, listen to, and work with each other.

The basic practices inherent to cooperative learning include a number of behavioral skills which include: simultaneous interaction, positive interdependence, and individual accountability. Within a cooperative learning environment, the students are encouraged to interact with members within the group. This freedom is usually not permissible within a traditional classroom setting. Positive interdependence comes from the achievement of individual students within the group and from the entire group as a whole. Individual accountability can be addressed with the aid of a variety of assessments. For instance, students can be given individual grades for a project, or they can be made aware of their part of a group grade.

Effective classroom management depends, in large part, upon the structure of the lesson. Not only does it involve the arrangement of the students within the group, but it is also dependent upon the manner in which individual lessons are designed and presented. These structures, designs, or activities are meant to improve such areas as team building, information sharing, thinking skills, communication skills, and content mastery. A brief list of classroom structures and lesson designs include: brainstorming, jigsaw, numbered heads together, rally table, round robin, roundtable, student teams achievement division (STAD), team projects, and think pair share. A detailed review of each activity can be found in Cooperative Learning (18).

By improving their note taking skills, students should be able to utilize, practice, and/or engage in summarizing, comprehension connectors, and structured note taking. For those reasons, I intend to teach my students the highly successful method of note taking that was developed by Walter Pauk, an English professor at Cornell University in the 1950's. The Cornell Method, as it is referred to, involves writing a key word, phrase, or concept on the left hand side of a sheet of paper. In a column, on the right hand side of the sheet of paper, relevant material about the concept is written in short sentences or phrases. Finally, at the bottom of the page, the material listed is then summarized into a short paragraph. This widely used method enables students to improve their skills in summarizing material presented in both lecture and written form (19).

In order to address and improve reading comprehension, my students will participate in reciprocal teaching techniques. This is another cooperative learning activity which is designed to encompass four skills: summarizing, questioning, clarifying, and predicting. Each student within the group will be responsible for reading a specific section within their textbook or assigned reading material, summarizing that material, and reporting out to the rest of his or her group. This pedagogical strategy has been reported to be successful in both small groups as well as in large classroom settings (20).

Classroom Activities

Activity 1: Introduction to Biological Membranes

Unit 1 of the standardized curriculum for chemistry, Matter and Energy, focuses on the fundamental changes that matter undergoes, the conservation of energy during these changes, as well as, accuracy and precision in measurement. As part of the content objectives within this unit, scientific notation is taught in conjunction with computational applications involving dimensional analysis. This activity is designed to address Pennsylvania State Standards 3.1.10 D, 3.4.10 A, 3.7.10 B, and 3.7.10 C. The students will view the film clip entitled "Powers of Ten" which takes the students on a visual journey spanning approximately forty powers of ten (21). After viewing the film clip, the students will be assigned a cooperative research project involving groups of four students. Each group will prepare a ten minute power point presentation on biological membranes. Material to be considered during the course of their research include: the compositional makeup of biological membranes, differences between hydrophobic, hydrophilic, and amphiphilic molecules, the functional role(s) of membrane bound proteins and the expenditure of energy during the transport of molecules and/or ions across the membrane. The purpose of this activity is twofold. The primary goal is to have the students learn about the structural organization and functions of biological membranes. As a side benefit, they will gain insight into the use of power point software culminating in the production of a coherent power point presentation. The guidelines to be followed are those established by Kathleen Bauer (22).

Activity 2: The Effect of Concentration on Diffusion

This activity is meant to be incorporated into Unit 4: "Ionic Bonds and Nomenclature" of the standardized curriculum for chemistry. It is an adaptation of an experiment from Vernier's Biology with Calculators (23). The main objective of this laboratory exercise is for the students to examine the effect of varying concentrations of salt solutions on the diffusion through a semi-permeable membrane. With the aid of a Vernier conductivity probe, LabPro interface, and a Texas Instruments TI-84 calculator, the data collected will enable the students to compare the diffusion rates and conductivity of a number of solutions containing varying amounts of salt. The units to be used for the diffusion rates are mg/L/s whereas the units for conductivity are μS where S stands for siemens the SI unit for conductance. Numerically, it is equivalent to one ampere per volt. In addition, by using a variety of chloride salt solutions containing different alkali metals the students will be able to compare the rate of diffusion to the ionic radius of selected ions. The table below lists the ionic radii for a number of alkali metals (24).

Table 1: Ionic radii for selected elements.

Alkali Metal	Ionic Radius (nm)
Lithium	0.06
Sodium	0.095
Potassium	0.133
Cesium	0.169

Activity 3: Molecular Modeling of Phospholipids and Proteins

"Covalent Bonds and Nomenclature" is the title of Unit 5 which emphasizes the properties and structures of molecular compounds. Among the behavioral objectives set forth by the School District of Philadelphia is the ability of the students to construct molecular models of covalent compounds. This activity relies on the ability of the students to construct a number of molecular models using the following LAB-AIDS kits: #511 Chemistry of Fats and #512 Chemistry of Proteins. The students will obtain the structural formulas for glycerol, in addition to the fatty acids and amino acids listed below.

Table 2: Selected amino acids and fatty acids of biological importance.

Amino Acids	Saturated Fatty Acids	Unsaturated Fatty Acids
Alanine	Myristic Acid	Palmitoleic Acid
Aspartic Acid	Palmitic Acid	Oleic Acid
Glutamic Acid	Stearic Acid	Elaidic Acid
Glycine	Arachidic Acid	Vaccenic Acid
Leucine	Behenic Acid	Linoleic Acid
Lysine	Lignoceric Acid	Eleostearic Acid

Methionine
Serine
Threonine
Valine

Arachidonic Acid
Nervonic Acid

Using the aforementioned kits, the students will construct a phospholipid containing one saturated and on unsaturated fatty acid and a dipeptide containing two different amino acids. In this activity, the students will be expected to distinguish saturated fatty acids from unsaturated fatty acids, identify the structure of a peptide bond, and explain the significance of dehydration synthesis.

Activity 4: Intermolecular Forces

This activity is intended to coincide with Unit 9 of the standardized curriculum for chemistry. As the primary goal of the unit, the students will relate the various intermolecular forces to molecular structure. In this activity, the students will create a ten minute power point presentation on the forces involved in the primary, secondary, tertiary, and quaternary structures of proteins. In addition, molecular modeling software will be utilized for visualizing the different molecular structure of various proteins. RasMol is ideal for this project due to the number of molecular structures in its library.

Activity 5: Calculations of Gibbs Free Energy

Unit 11 of the standardized curriculum focuses on the dynamics of chemical reactions. In particular, the conditions affecting chemical equilibrium will be examined. This activity will allow students the opportunity to improve their math skills by calculating the change in free energy, ΔG, of various chemical reactions and determining whether or not the reactions will occur spontaneously. Throughout this activity the students will use the following equation for substances.

$$\Delta G = RT\ 2.303 \log_{10}[X]_{out} / [X]_{in}$$

The value of R to be used in these calculations is 1.99 cal/ mol degree Kelvin and T is the temperature in Kelvins. For ions, the students will use the following equation:

$$\Delta G = zFV_m$$

An additional equation, shown below, will be used for the transport of substances involving the co-transport of a specific ion.

$$\Delta G = RT\ 2.303 \log_{10} [X]_{out} / [X]_{in} + zFV_m$$

As a brief reminder, z is the valence or ionic charge, F is the Faraday constant or 2.3 x 10^4 cal/mol V, and V_m is the membrane potential in millivolts. The intracellular and extracellular concentrations for several selected ions and substances are listed in the table below:

Table 3: Intracellular and extracellular concentration of ions and substances.

Ions	Intracellular Concentration (mM)	Extracellular Concentration (mM)
Na^+	10	140
K^+	125	5
Mg^{2+}	0.2	2
Cl^-	10	105
Substances		
Glucose	0.5	5
Glutamic acid	0.1	20

Student Problems:

1. Calculate the ΔG for the transport of each ion into a typical eukaryotic cell using the appropriate equation and determine whether or not the reaction will occur spontaneously. Assume that the membrane potential for the cell is -70 mV.
2. Calculate the ΔG for the facilitated diffusion of glucose.
3. Calculate the ΔG for the co-transport of Na^+ and glucose across a cell with a membrane potential of -65 mV.
4. Calculate the ΔG for the active transport of glutamic acid into a cell having a membrane potential of -58 mV (assume at physiological pH glutamic acid has a net charge of 1-).

The temperature for all of the above problems is taken to be 37° C.

Annotated Bibliography/ Resources

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This article on membrane transport gives a brief overview of facilitated diffusion and active transport.

Appendices-Content Standards

The Pennsylvania academic standards for science and technology, which will be addressed in this curriculum unit, were taken directly from the Pennsylvania Teacher's Desk Reference and Critical Thinking Guide (1) and include the following:

3.1.10 Unifying Themes: The unifying themes focus on the fundamental concepts and processes that form the framework upon which science and technology are organized, such as: the structure of matter.

D. Apply scale as a way of relating concepts and ideas to one another by some measure. Apply dimensional analysis and scale as a ratio. Convert one scale to another.

E. Describe patterns of change in nature, physical and man made systems. Describe how fundamental science and technology concepts are used to solve practical problems (e.g., momentum, Newton's law of universal, gravitation, tectonics, conservation of mass and energy, cell theory, theory of evolution, atomic theory, theory of relativity, Pasteur's germ theory, relativity, heliocentric theory, gas laws, feedback systems).

3.4.10 Physical Science, Chemistry and Physics: Students study the relationship between matter, atomic structure and its activity.

A. Explain concepts about the structure and properties of matter.

Know that atoms are composed of even smaller sub-atomic structures whose properties are measurable. Describe various types of chemical reactions by applying the laws of conservation of mass and energy.

B. Analyze energy sources and transfers of heat.

Evaluate energy changes in chemical reactions.

C. Distinguish among the principles of force and motion.

Describe and measure the motion of sound, light and other objects.

Know Newton's laws of motion (including inertia, action and reaction) and gravity and apply them to solve problems related to forces and mass.

3.7.10 Technological Devices: Technology enhances the students' abilities to identify problems and determine solutions.

A. Identify and safely use a variety of tools, basic machines, materials and techniques to solve problems and answer questions.

Select and safely apply appropriate tools, materials and processes necessary to solve complex problems.

B. Apply appropriate instruments and apparatus to examine a variety of objects and processes. Describe and use appropriate instruments to gather and analyze data. Compare and contrast different scientific measurement systems; select the best measurement system for a specific situation. Apply accurate measurement knowledge to solve everyday problems.

3.8.10 Science, Technology and Human Endeavors: Scientific knowledge and societal needs often create a demand for new technology. Conversely, new technology advances scientific knowledge. Both influence society through the impact of their products and processes.

C. Evaluate possibilities, consequences and impacts of scientific and technological solutions.

Relate scientific and technological advancements in terms of cause and effect. Analyze the impacts on society of accepting or rejecting scientific and technological advances.