Massachusetts Science and Technology/Engineering High School Standards

Earth and Space Science
Biology
Chemistry
Introductory Physics
Technology/Engineering

(Revised January 2006)

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Introduction

All students need to achieve a sufficient level of scientific literacy to enable them to succeed in post-secondary education, in careers, and as contributing members of a democratic society. The 2006 revised *Science and Technology/Engineering High School Standards* list both *science content* and *scientific inquiry skills* needed to achieve scientific literacy.

Summary of Key Revisions to the 2001 High School Science and Technology/Engineering Standards

The *2001 Massachusetts Science and Technology/Engineering Curriculum Framework* was reviewed and revised to address concerns raised by the field since the discipline-specific high school standards were first adopted in 2001. The 2001 framework, for the first time, articulated standards for full-year high school courses in Earth and space science, biology, chemistry, introductory physics, and technology/ engineering. The framework identified a subset of "core" standards for each course that were designed to serve as the basis for high school MCAS assessments. Some educators in the field expressed concerns that standards not identified as core may not be taught, if not tested by MCAS. The other major concern expressed was the absence of standards that would promote the teaching and learning of science through laboratory experiences. Both of these concerns, as well as an overall improvement of the standards for clarity and specificity, have been addressed in the revised standards. A summary of the key revisions follows:

- The revised content standards are presented as a single list of content standards for each course, with no differentiation between core and non-core standards, making all standards subject to local and state assessment.
- In addition to the content standards, each course now includes four Scientific Inquiry Skills Standards.
- The wording of some of the content standards has been changed in order to clarify the standard or increase the specificity.
- The standards for the two-year integrated science course in grades 9 and 10 were eliminated.
- Each course now includes a list of mathematical skills necessary for a solid understanding of the course.

About the Content and Scientific Inquiry Skills Standards

In addition to discipline-specific content standards that describe the scientific concepts students should acquire in each of the disciplines (Earth and Space Science, Biology, Chemistry, Introductory Physics, and Technology/Engineering), this revision includes Standards for Scientific Inquiry Skills. These standards describe the skills and knowledge scientists use to inquire about natural phenomena through experimentation, fieldwork, and through reading and critiquing published investigations in scientific journals and articles.

These inquiry skills should also be addressed in the science classroom. Accordingly, in science classes students participate in investigations and laboratory experiences that are purposeful activities designed to develop student understanding of science concepts. Students are provided with experiences that allow them to raise questions, draw upon their prior knowledge, and build new understandings and skills. Students also communicate scientific ideas by presenting, reviewing, and critiquing scientific information or findings with others.

The Scientific Inquiry Skills Standards (coded SIS), listed below, are common to each of the disciplines.

SIS1. Make observations, raise questions, and formulate hypotheses.
SIS2. Design and conduct scientific investigations.
SIS3. Analyze and interpret results of scientific investigations.
SIS4. Communicate and apply the results of scientific investigations.

Optimally, the Scientific Inquiry Skills Standards should be taught and assessed in conjunction with the Content Standards, not as stand-alone skills. Scientific skills should be assessed through examples drawn from the Earth and Space Science, Biology, Chemistry, and Introductory Physics standards so students understand that what is known in science does not stand separate from how it is known. Students need to use scientific knowledge and skills together to develop conceptual understandings and abilities that lead to scientific literacy needed in civic life and the workplace.

Preparation for post-secondary opportunities is yet another reason to provide regular laboratory and fieldwork experiences in science and technology/engineering courses. The Massachusetts Board of Higher Education's *Admissions Standards for the Massachusetts State Colleges and University* states that three science courses, including two courses with laboratory work, must be completed in order to fulfill the minimum science requirement for admission to the Commonwealth's four-year public institutions. The high school courses based on the standards presented in this document should all include substantial laboratory and/or fieldwork to allow all students the opportunity to meet or exceed this requirement of the Massachusetts Board of Higher Education.

About the Mathematical Skills

Engaging in science and technology/engineering often involves the use of mathematics to analyze and support findings of investigations or the design process. Most of the mathematical skills needed for science and technology/engineering courses should have been gained through the achievement of standards outlined in the *Mathematics Framework* appropriate to the student's grade level. However, there may be a few specialized mathematical skills needed in each science and technology/ engineering course that are not included in the *Mathematics Framework*. This document lists commonly applied mathematical skills for each discipline found in the *Mathematics Framework* as well as the specialized mathematical skills that are not detailed in the Mathematics framework. The mathematical skills listed are necessary for a solid understanding of the science or technology/engineering course.

Organization of the Standards

The high school standards for Introductory Physics, Biology, Earth and Space Science, Chemistry, and Technology/Engineering are presented in a similar format:

I. **Content Standards** describe essential knowledge and conceptual understandings of the discipline that students should acquire. The standards are grouped by topics and broad concepts to which the learning standards are related.

II. **Scientific Inquiry Skills Standards** define what students need to be able to do in order to carry out investigations or experiments as they engage in scientific inquiry. There are four general standards with specific skills listed below each. The Technology/Engineering Standards list the Steps of the Engineering Design Process in place of Scientific Inquiry Skills Standards.

III. **Mathematical Skills** identify common skills from the *Mathematics Framework* that students will apply in the course. This section also lists skills that are not detailed in the *Mathematics Framework* but are necessary for a solid understanding of the discipline.

Science and Technology/Engineering High School Standards

Earth and Space Science High School Standards

Learning Standards for a full first-year course

The Earth and Space Science high school standards address the following topics: *Matter and Energy in the Earth System, Energy in the Earth's System, Earth's Processes and Cycles,* and *The Origin and Evolution of the Universe.*

At the high school level, students review geological, meteorological, oceanographic, and astronomical data to learn about Earth's matter, energy, processes, and cycles. Through these data they also learn about the origin and evolution of the universe. Students gain knowledge about Earth's internal and external energy sources, local weather and climate, and the dynamics of ocean currents. Students learn about the renewable and non-renewable energy resources of Earth and what impact these have on the environment. Through learning about Earth's processes and cycles, students gain a better understanding of nitrogen and carbon cycles, the rock cycle, and plate tectonics. Students also learn about the origin of the universe and how scientists are currently studying deep space and the solar system.

I. Content Standards

1. Matter and Energy in the Earth System
Broad Concepts: The entire Earth system and its various cycles are driven by energy. Earth has both internal and external sources of energy. Two fundamental energy concepts included in the Earth system are gravity and electromagnetism.

1.1 Identify Earth's principal sources of internal and external energy, such as, radioactive decay, gravity, and solar energy.
1.2 Describe the characteristics of electromagnetic radiation and give examples of its impact on life and Earth's systems.
1.3 Explain how the transfer of energy through radiation, conduction, and convection contributes to global atmospheric processes, such as, storms, winds, and currents.
1.4 Provide examples of how the unequal heating of Earth and the Coriolis effect influence global circulation patterns, and show how they impact Massachusetts weather and climate, such as, global winds, convection cells, land/sea breezes, and mountain/valley breezes.
1.5 Explain how the revolution of Earth around the Sun and the inclination of Earth on its axis cause Earth's seasonal variations (equinoxes and solstices).
1.6 Describe the various conditions associated with frontal boundaries and cyclonic storms (such as, thunderstorms, winter storms [nor'easters], hurricanes, and tornadoes) and their impact on human affairs, including storm preparations.
1.7 Explain the dynamics of oceanic currents, including upwelling, deep-water currents, the Labrador Current and the Gulf Stream, and their relationship to global circulation within the marine environment and climate.
1.8 Read, interpret, and analyze a combination of ground-based observations, satellite data, and computer models to demonstrate Earth systems and their interconnections.

2. Energy Resources in the Earth System
Broad Concept: Energy resources are used to sustain human civilization. The amount and accessibility of these resources influences their use and their impact on the environment.

2.1 Recognize, describe, and compare renewable energy resources (such as, solar, wind, water, and biomass) and nonrenewable energy resources (such as, fossil fuels and nuclear energy.)
2.2 Describe the effects on the environment and on the carbon cycle of using both renewable and nonrenewable sources of energy.

3. Earth Processes and Cycles
Broad Concepts: Earth is a dynamic interconnected system. The evolution of Earth has been driven by interactions between the lithosphere, hydrosphere, atmosphere, and biosphere. Over geologic time the internal motions of Earth have continuously altered the topography and geography of the continents and ocean basins by both constructive and destructive processes.

3.1 Explain how physical and chemical weathering leads to erosion and the formation of soils and sediments, and creates the various types of landscapes. Give examples that show the effects of physical and chemical weathering on the environment.
3.2 Describe the carbon cycle.
3.3 Describe the nitrogen cycle.
3.4 Explain how water flows into and through a watershed. Explain the role of aquifers, wells, porosity, permeability, water table, and runoff.
3.5 Describe the processes of the hydrologic cycle including evaporation, condensation, precipitation, surface runoff and groundwater percolation, infiltration, and transpiration.
3.6 Describe the rock cycle, and the processes that are responsible for the formation of igneous, sedimentary, and metamorphic rocks. Compare the physical properties of these rock types and the physical properties of common rock-forming minerals.
3.7 Describe the absolute and relative dating methods used to measure geologic time, such as, index fossils, radioactive dating, law of superposition, and crosscutting relationships.
3.8 Trace the development of a lithospheric plate from its growth at a divergent boundary (mid-ocean ridge) to its destruction at a convergent boundary (subduction zone). Recognize that alternating magnetic polarity is recorded in rock at mid-ocean ridges.
3.9 Explain the relationship between convection currents in Earth's mantle and the motion of the lithospheric plates.
3.10 Relate earthquakes, volcanic activity, tsunamis, mountain building and tectonic uplift to plate movements.
3.11 Explain how seismic data are used to reveal Earth's interior structure and to locate earthquake epicenters.
3.12 Describe the Richter scale of earthquake magnitude and the relative damage that is incurred by earthquakes of a given magnitude.

4. The Origin and Evolution of the Universe
Broad Concept: The origin of the universe, between 14 and 15 billion years ago, still remains one of the greatest questions in science. Gravity influences the formation and life

cycles of galaxies, including our own Milky Way Galaxy, stars, planetary systems, and residual material left from the creation of the solar system.

4.1 Explain the Big Bang Theory and discuss the evidence that supports it, such as, background radiation, and relativistic Doppler effect ~ "red shift".

4.2 Describe the influence of gravity and inertia on the rotation and revolution of orbiting bodies. Explain the sun-Earth-moon relationships, such as, day, year, solar/lunar eclipses and tides.

4.3 Explain how the sun, Earth, and solar system formed from a nebula of dust and gas in a spiral arm of the Milky Way Galaxy about 4.6 billion years ago.

II. Scientific Inquiry Skills Standards

Scientific literacy can be achieved by supporting students to inquire about geologic, meteorological, oceanographic, and astronomical phenomena. Scientific skills that are developed in Earth and Space Science include the inquiry skills presented below, as well as reading and interpreting maps, keys, and satellite, radar, and telescope imageries; using satellite and radar images and weather maps to illustrate weather forecasts; using seismic data to identify regions of seismic activity, and using data from various instruments that are used to study deep space and the solar system. The science curriculum should include substantial hands-on laboratory and field experiences, as appropriate, for students to develop and use scientific skills in Earth and Space Science.

SIS1. Make observations, raise questions, and formulate hypotheses.

Students will be able to:

- Observe the world around them from a scientific perspective.
- Pose questions and form hypotheses based on personal observations, scientific articles, experiments, and knowledge.
- Read, interpret, and examine the credibility and validity of scientific claims in different sources of information, such as scientific articles, advertisements, or media stories.

SIS2. Design and conduct scientific investigations.

Students will be able to:

- Articulate and explain the major concepts being investigated and the purpose of an investigation.
- Select required materials, equipment, and conditions for conducting an experiment.
- Identify independent and dependent variables.
- Write procedures that are clear and replicable.
- Employ appropriate methods for accurately and consistently
  - making observations;
  - making and recording measurements at an appropriate level of precision and;
  - collecting data or evidence in an organized way.
- Properly use instruments, equipment, and materials (such as scales, probeware, meter sticks, microscopes, computers, etc.) including: set-up, calibration (if required), technique, maintenance, and storage.
- Follow safety guidelines.

SIS3. Analyze and interpret results of scientific investigations.
Students will be able to:

- Present relationships between variables in appropriate forms.
    - Represent data and relationships between variables in charts and graphs.
    - Use appropriate technology (such as graphing software, etc.) and other tools.
- Use mathematical operations to analyze and interpret data results.
- Identify reasons for inconsistent results, such as sources of error or uncontrolled conditions, and assess the reliability of data.
- Use results of an experiment to develop a conclusion to an investigation that addresses the initial questions and supports or refutes the stated hypothesis.
- State questions raised by an experiment that may require further investigation.

SIS4. Communicate and apply the results of scientific investigations.
Students will be able to:

- Develop descriptions and explanations of scientific concepts that an investigation focused on.
- Review information, explain statistical analysis, and summarize data collected and analyzed from an investigation.
- Explain diagrams and charts that represent relationships of variables.
- Construct a reasoned argument and respond appropriately to critical comments and questions.
- Use language and vocabulary appropriately, speak clearly and logically, and use appropriate technology (such as presentation software, etc.) and other tools to present findings.
- Use and refine scientific models that simulate physical processes or phenomena.

III. Mathematical Skills

Students are expected to know the content of the *Massachusetts Mathematics Curriculum Framework, November 2000* through Grade 8. Below are some specific skills from the *Mathematics Framework* that students in this course should have the opportunity to apply:

- ✓ Construct and use tables and graphs to interpret data sets.
- ✓ Solve simple algebraic expressions.
- ✓ Perform basic statistical procedures to analyze the center and spread of data.
- ✓ Measure with accuracy and precision (length, volume, mass, temperature, time, etc.)
- ✓ Convert within a unit (such as, centimeters to meters).
- ✓ Use common prefixes such as milli-, centi-, and kilo-.
- ✓ Use scientific notation, where appropriate.
- ✓ Use ratio and proportion in the solution of problems.

The following skills are not detailed in the *Mathematics Framework*, but are necessary for a solid understanding in this course:

- ✓ Determine percent error from experimental and accepted values.
- ✓ Use appropriate metric/standard international (SI) units of measurement for mass (kg); length (m); time (s); force (N); speed (m/s); acceleration ($m \bullet s^{-2}$); and frequency (Hz).
- ✓ Use Celsius and Kelvin scales.

Biology High School Standards

Learning Standards for a full first-year course

The biology high school standards address the following topics: *Chemistry of Life*; *Cell Biology*; *Genetics*; *Vertebrate Anatomy and Physiology*; *Evolution and Biodiversity*; and *Ecology*.

At the high school level, students study life by examining systems from the molecular level through cell biology and genetics, to the tissue and organ level in vertebrate anatomy and physiology, and at the level of organisms and populations through ecology. A solid understanding of the processes of life allows students to make scientifically informed decisions related to their health, and to the health of the planet.

Unifying these diverse topics of study is the concept of organic evolution, which is fundamental to understanding modern biology. Students learn that the DNA molecule is the functional unit of the evolutionary process, and that it dictates all of the physical traits that are inherited across generations. They learn that variation in traits also is inherited and that the unit of inheritance is the gene. Students learn that variation can give some individuals a selective advantage – perhaps due to morphological, physiological or behavioral traits – that allow them to survive better, and to be more competitive in a given environment. This understanding provides students with a framework for explaining why there are so many different kinds of organisms on Earth, why organisms of distantly related species share biochemical, anatomical, and functional characteristics, why species become extinct, and how different kinds of organisms are related to one another.

Biotechnology

Biotechnology is a rapidly expanding field of biology that uses a growing set of techniques to derive valuable products from organisms and their cells. Biotechnology is already commonly used to identify potential suspects or exonerate persons wrongly accused of crimes, determine paternity, diagnose diseases, make high-yield pest-resistant crops, and treat genetic ailments. Educators should recognize the importance of introducing students to biotechnology so that they may better understand the molecular basis of heredity and critically evaluate the benefits and risks of this technology.

I. Content Standards

1. The Chemistry of Life

Broad Concept: Chemical elements form organic molecules that interact to perform the basic functions of life.

1.1 Recognize that biological organisms are composed primarily of very few elements. The six most common are C, H, N, O, P, S.

1.2 Describe the basic molecular structures and primary functions of the four major categories of organic molecules (carbohydrates, lipids, proteins, and nucleic acids).

1.3 Explain the role of enzymes as catalysts that lower the activation energy of biochemical reactions. Identify factors, such as pH and temperature, which have an effect on enzymes.

2. Cell Biology

Broad Concept: Cells have specific structures and functions that make them distinctive. Processes in a cell can be classified broadly as growth, maintenance, and reproduction.

2.1 Relate cell parts/organelles (plasma membrane, nuclear envelope, nucleus, nucleolus, cytoplasm, mitochondrion, endoplasmic reticulum, Golgi apparatus, lysosome, ribosome, vacuole, cell wall, chloroplast, cytoskeleton, centriole, cilium, flagellum, pseudopod) to their functions. Explain the role of cell membranes as a highly selective barrier (diffusion, osmosis, facilitated diffusion, and active transport).

2.2 Compare and contrast, at the cellular level, prokaryotes and eukaryotes (general structures and degrees of complexity).

2.3 Use cellular evidence (such as cell structure, cell number, and cell reproduction) and modes of nutrition to describe six kingdoms (Archaebacteria, Eubacteria, Protista, Fungi, Plantae, Animalia).

2.4 Identify the reactants, products, and basic purposes of photosynthesis and cellular respiration. Explain the interrelated nature of photosynthesis and cellular respiration in the cells of photosynthetic organisms.

2.5 Explain the important role that ATP serves in metabolism.

2.6 Describe the cell cycle and the process of mitosis. Explain the role of mitosis in the formation of new cells, and its importance in maintaining chromosome number during asexual reproduction.

2.7 Describe how the process of meiosis results in the formation of haploid cells. Explain the importance of this process in sexual reproduction, and how gametes form diploid zygotes in the process of fertilization.

2.8 Compare and contrast a virus and a cell in terms of genetic material and reproduction.

3. Genetics

Broad Concept: Genes allow for the storage and transmission of genetic information. They are a set of instructions encoded in the nucleotide sequence of each organism. Genes code for the specific sequences of amino acids that comprise the proteins that are characteristic of that organism.

3.1 Describe the basic structure (double helix, sugar/phosphate backbone, linked by complementary nucleotide pairs) of DNA, and describe its function in genetic inheritance.

3.2 Describe the basic process of DNA replication and how it relates to the transmission and conservation of the genetic code. Explain the basic processes of transcription and translation, and how they result in the expression of genes. Distinguish among the end products of replication, transcription, and translation.

3.3 Explain how mutations in the DNA sequence of a gene may or may not result in phenotypic change in an organism. Explain how mutations in gametes may result in phenotypic changes in offspring.

3.4 Distinguish among observed inheritance patterns caused by several types of genetic traits (dominant, recessive, incomplete dominance, codominant, sex-linked, polygenic, and multiple alleles).
3.5 Describe how Mendel's laws of segregation and independent assortment can be observed through patterns of inheritance (such as dihybrid crosses).
3.6 Use a Punnett Square to determine the probabilities for genotype and phenotype combinations in monohybrid crosses.

4. Anatomy and Physiology

Broad Concept: There is a relationship between the organization of cells into tissues, and tissues into organs. The structure and function of organs determine their relationships within body systems of an organism. Homeostasis allows the body to perform its normal functions.

4.1 Explain generally how the digestive system (mouth, pharynx, esophagus, stomach, small and large intestines, rectum) converts macromolecules from food into smaller molecules that can be used by cells for energy and for repair and growth.
4.2 Explain how the circulatory system (heart, arteries, veins, capillaries, red blood cells) transports nutrients and oxygen to cells and removes cell wastes. Describe how the kidneys and the liver are closely associated with the circulatory system as they perform the excretory function of removing waste from the blood. Recognize that kidneys remove nitrogenous wastes, and the liver removes many toxic compounds from blood.
4.3 Explain how the respiratory system (nose, pharynx, larynx, trachea, lungs, alveoli) provides exchange of oxygen and carbon dioxide.
4.4 Explain how the nervous system (brain, spinal cord, sensory neurons, motor neurons) mediates communication between different parts of the body and the body's interactions with the environment. Identify the basic unit of the nervous system, the neuron, and explain generally how it works.
4.5 Explain how the muscular/skeletal system (skeletal, smooth and cardiac muscle, bones, cartilage, ligaments, tendons) works with other systems to support and allow for movement. Recognize that bones produce both red and white blood cells.
4.6 Recognize that the sexual reproductive system allows organisms to produce offspring that receive half of their genetic information from their mother and half from their father and that sexually produced offspring resemble, but are not identical to, either of their parents.
4.7 Recognize that communication between cells is required for coordination of body functions. The nerves communicate with electrochemical signals, hormones circulate through the blood, and some cells produce signals to communicate only with nearby cells.
4.8 Recognize that the body's systems interact to maintain homeostasis. Describe the basic function of a physiological feedback loop.

5. Evolution and Biodiversity

Broad Concept: Evolution is the result of genetic changes that occur in constantly changing environments. Over many generations, changes in the genetic make-up of populations may affect biodiversity through speciation and extinction.

5.1 Explain how evolution is demonstrated by evidence from the fossil record, comparative anatomy, genetics, molecular biology, and examples of natural selection.
5.2 Describe species as reproductively distinct groups of organisms. Recognize that species are further classified into a hierarchical taxonomic system (kingdom, phylum, class, order, family, genus, species) based on morphological, behavioral, and molecular similarities. Describe the role that geographic isolation can play in speciation.
5.3 Explain how evolution through natural selection can result in changes in biodiversity through the increase or decrease of genetic diversity from a population.

6. Ecology
Broad Concept: Ecology is the interaction among organisms and between organisms and their environment.
6.1 Explain how birth, death, immigration, and emigration influence population size.
6.2 Analyze changes in population size and biodiversity (speciation and extinction) that result from the following: natural causes, changes in climate, human activity, and the introduction of invasive, non-native species.
6.3 Use a food web to identify and distinguish producers, consumers, and decomposers, and explain the transfer of energy through trophic levels. Describe how relationships among organisms (predation, parasitism, competition, commensalism, and mutualism) add to the complexity of biological communities.
6.4 Explain how water, carbon, and nitrogen cycle between abiotic resources and organic matter in an ecosystem and how oxygen cycles through photosynthesis and respiration.

II. Scientific Inquiry Skills Standards

Scientific literacy can be achieved by supporting students to inquire about the biological world. Engaging students in scientific inquiry allows them to develop conceptual understandings and scientific skills that are necessary to be informed decision-makers. The science curriculum should include substantial hands-on laboratory and field experiences, as appropriate, for students to develop and use these skills in a Biology course.

SIS1. Make observations, raise questions, and formulate hypotheses.
Students will be able to:
- Observe the world around them from a scientific perspective.
- Pose questions and form hypotheses based on personal observations, scientific articles, experiments, and knowledge.
- Read, interpret, and examine the credibility and validity of scientific claims in different sources of information, such as scientific articles, advertisements, or media stories.

SIS2. Design and conduct scientific investigations.
Students will be able to:

- Articulate and explain the major concepts being investigated and the purpose of an investigation.
- Select required materials, equipment, and conditions for conducting an experiment.
- Identify independent and dependent variables.
- Write procedures that are clear and replicable.
- Employ appropriate methods for accurately and consistently
  - making observations;
  - making and recording measurements at an appropriate level of precision and;
  - collecting data or evidence in an organized way.
- Properly use instruments, equipment, and materials (such as scales, probeware, meter sticks, microscopes, computers, etc.) including: set-up, calibration (if required), technique, maintenance, and storage.
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SIS3. Analyze and interpret results of scientific investigations.
Students will be able to:
- Present relationships between variables in appropriate forms.
  - Represent data and relationships between variables in charts and graphs.
  - Use appropriate technology (such as graphing software, etc.) and other tools.
- Use mathematical operations to analyze and interpret data results.
- Identify reasons for inconsistent results, such as sources of error or uncontrolled conditions, and assess the reliability of data.
- Use results of an experiment to develop a conclusion to an investigation that addresses the initial questions and supports or refutes the stated hypothesis.
- State questions raised by an experiment that may require further investigation.

SIS4. Communicate and apply the results of scientific investigations.
Students will be able to:
- Develop descriptions and explanations of scientific concepts that an investigation focused on.
- Review information, explain statistical analysis, and summarize data collected and analyzed from an investigation.
- Explain diagrams and charts that represent relationships of variables.
- Construct a reasoned argument and respond appropriately to critical comments and questions.
- Use language and vocabulary appropriately, speak clearly and logically, and use appropriate technology (such as presentation software, etc.) and other tools to present findings.
- Use and refine scientific models that simulate physical processes or phenomena.

III. Mathematical Skills

Students are expected to know the content of the *Massachusetts Mathematics Curriculum Framework, November 2000* through Grade 8. Below are some specific skills from the *Mathematics Framework* that students in this course should have the opportunity to apply:

- ✓ Construct and use tables and graphs to interpret data sets.
- ✓ Solve simple algebraic expressions.
- ✓ Perform basic statistical procedures to analyze the center and spread of data.
- ✓ Measure with accuracy and precision (length, volume, mass, temperature, time, etc.)
- ✓ Convert within a unit (such as, centimeters to meters).
- ✓ Use common prefixes such as milli-, centi-, and kilo-.
- ✓ Use scientific notation, where appropriate.
- ✓ Use ratio and proportion in the solution of problems.

The following skills are not detailed in the *Mathematics Framework*, but are necessary for a solid understanding in this course:

- ✓ Determine the correct number of significant figures.
- ✓ Determine percent error from experimental and accepted values.
- ✓ Use appropriate metric/standard international (SI) units of measurement for mass (kg); length (m); and time (s).
- ✓ Use Celsius the scale.

Chemistry High School Standards

Learning Standards for a full first-year course

The chemistry high school standards address the following topics: *Properties of Matter*; *Atomic Structure and Nuclear Chemistry*; *Periodicity*; *Chemical Bonding*; *Chemical Reactions and Stoichiometry*; *States of Matter, Kinetic Theory, and Thermochemistry*; *Solutions, Rates of Reactions, and Equilibrium*; *and Acids, Bases and Reduction-Oxidation Reactions*.

At the high school level, students learn about the properties of matter and how these properties help to organize elements on the periodic table. Through history, students develop a better understanding of the structure of the atom. Students develop an understanding of chemical reactions including the involvement of energy and sub-atomic particles to better understand the nature of chemical changes. By learning about various chemical reactions, such as oxidation-reduction, combustion, and decomposition, students learn about chemical reactions that occur around us everyday. Students also gain a deeper understanding of acids and bases, rates of reactions, and factors that affect those rates. From calculating stoichiometry problems and molar concentrations, students learn about proportionality and strengthen their mathematical skills.

I. Content Standards

1. Properties of Matter

Broad Concept: Physical and chemical properties reflect the nature of the interactions between molecules or atoms and can be used to classify and describe matter.

1.1 Identify and explain physical properties (such as density, melting point, boiling point, conductivity, and malleability) and chemical properties (such as the ability to form new substances). Distinguish between chemical and physical changes.

1.2 Explain the difference between pure substances (elements and compounds) and mixtures. Differentiate between heterogeneous and homogeneous mixtures.

1.3 Describe the three normal states of matter (solid, liquid, gas) in terms of energy, particle motion, and phase transitions.

2. Atomic Structure and Nuclear Chemistry

Broad Concept: Atomic models are used to explain atoms and help us understand the interaction of elements and compounds observed on a macroscopic scale. Nuclear chemistry deals with radioactivity, nuclear processes, and nuclear properties. Nuclear reactions produce tremendous amounts of energy and the formation of the elements.

2.1 Recognize discoveries from Dalton (atomic theory), Thomson (the electron), Rutherford (the nucleus), and Bohr (planetary model of atom) and understand how these discoveries lead to the modern theory.

2.2 Describe Rutherford's "gold foil" experiment that led to the discovery of the nuclear atom. Identify the major components (protons, neutrons, and electrons) of the nuclear atom and explain how they interact.

2.3 Interpret and apply the laws of conservation of mass, constant composition (definite proportions), and multiple proportions.
2.4 Write the electron configurations for the first twenty elements of the periodic table.
2.5 Identify the three main types of radioactive decay (alpha, beta, and gamma) and compare their properties (composition, mass, charge, and penetrating power).
2.6 Describe the process of radioactive decay by using nuclear equations and explain the concept of half-life for an isotope, for example, C-14 is a powerful tool in determining the age of objects.
2.7 Compare and contrast nuclear fission and nuclear fusion.

3. Periodicity

Broad Concept: Repeating (periodic) patterns of physical and chemical properties occur among elements that define families with similar properties. The periodic table displays this repeating pattern, which is related to an atom's outermost electrons.

3.1 Explain the relationship of an element's position on the periodic table to its atomic number. Identify families (groups) and periods on the periodic table.
3.2 Use the periodic table to identify the three classes of elements: metals, nonmetals, and metalloids.
3.3 Relate the position of an element on the periodic table to its electron configuration and compare its reactivity with other elements in the table.
3.4 Identify trends on the periodic table (ionization energy, electronegativity, and relative size of atoms and ions).

4. Chemical Bonding

Broad Concept: Atoms bond with each other by transferring or sharing valence electrons to form compounds.

4.1 Explain how atoms combine to form compounds through both ionic and covalent bonding. Predict chemical formulas based on the number of valence electrons.
4.2 Draw Lewis dot structures for simple molecules and ionic compounds.
4.3 Use electronegativity to explain the difference between polar and nonpolar covalent bonds.
4.4 Use valence-shell electron-pair repulsion theory (VSEPR) to predict the electron geometry (linear, trigonal planar, and tetrahedral) of simple molecules.
4.5 Identify how hydrogen bonding in water affects a variety of physical, chemical, and biological phenomena (such as, surface tension, capillary action, density, and boiling point).
4.6 Name and write the chemical formulas for simple ionic and molecular compounds, including those that contain the polyatomic ions: ammonium, carbonate, hydroxide, nitrate, phosphate, and sulfate.

5. Chemical Reactions and Stoichiometry

Broad Concept: In a chemical reaction, one or more reactants are transformed into one or more new products. Chemical equations represent the reaction and must be balanced. The conservation of atoms in a chemical reaction leads to the ability to calculate the amount of products formed and reactants used (stoichiometry).

5.1 Balance chemical equations by applying the laws of conservation of mass and constant composition (definite proportions).
5.2 Classify chemical reactions as synthesis (combination), decomposition, single displacement, double displacement, and combustion.
5.3 Use the mole concept to determine the number of particles and the molar mass of elements and compounds.
5.4 Determine percent compositions, empirical formulas, and molecular formulas.
5.5 Calculate the mass-to-mass stoichiometry for a chemical reaction.
5.6 Calculate percent yield in a chemical reaction.

6. States of Matter, Kinetic Molecular Theory, and Thermochemistry
Broad Concept: Gas particles move independently of each other and are far apart. Their behavior can be modeled by the kinetic molecular theory. In liquids and solids, unlike gases, the particles are close to each other. The driving forces of chemical reactions are energy and entropy. The reorganization of atoms in chemical reactions results in the release or absorption of heat energy.
6.1 Using the kinetic molecular theory, explain the behavior of gases and the relationship between pressure and volume (Boyle's law), volume and temperature (Charles's law), pressure and temperature (Gay-Lussac's law), and the number of particles in a gas sample (Avogadro's hypothesis). Use the combined gas law to determine changes in pressure, volume, and temperature.
6.2 Perform calculations using the ideal gas law. Understand the molar volume at 273K and 1 atmosphere (STP).
6.3 Using the kinetic molecular theory, describe and contrast the properties of gases, liquids, and solids. Explain, at the molecular level, the behavior of matter as it undergoes phase transitions.
6.4 Describe the law of conservation of energy. Explain the difference between an endothermic process and an exothermic process.
6.5 Recognize that there is a natural tendency for systems to move in a direction of disorder or randomness (entropy).

7. Solutions, Rates of Reaction, and Equilibrium
Broad Concept: Solids, liquids, and gases dissolve to form solutions. Rates of reaction and chemical equilibrium are dynamic processes that are significant in many systems (biological, ecological, and geological).
7.1 Describe the process by which solutes dissolve in solvents.
7.2 Calculate concentration in terms of molarity. Use molarity to perform solution dilution and solution stoichiometry.
7.3 Identify and explain the factors that affect the rate of dissolving, such as, temperature, concentration, surface area, pressure, and mixing.
7.4 Compare and contrast qualitatively the properties of solutions and pure solvents (colligative properties such as boiling point and freezing point).
7.5 Identify the factors that affect the rate of a chemical reaction (temperature, mixing, concentration, particle size, surface area, and catalyst).

7.6 Predict the shift in equilibrium when the system is subjected to a stress (LeChatelier's principle) and identify the factors that can cause a shift in equilibrium (concentration, pressure, volume, temperature).

8. Acids and Bases and Oxidation-Reduction Reactions
Broad Concept: Acids and bases are important in numerous chemical processes that occur around us, from industrial procedures to biological ones, from the laboratory to the environment. Oxidation-reduction reactions occur when one substance transfers electrons to another substance and constitutes a major class of chemical reactions.
8.1 Define the Arrhenius theory of acids and bases in terms of the presence of hydronium and hydroxide ions in water and the Bronsted-Lowry theory of acids and bases in terms of proton donor and acceptor.
8.2 Relate hydrogen ion concentrations to the pH scale, and to acidic, basic, and neutral solutions. Compare and contrast the strength of various common acids and bases such as vinegar, baking soda, soap, and citrus juice.
8.3 Explain how a buffer works.
8.4 Describe oxidation and reduction reactions and give some every day examples, such as, fuel burning, corrosion. Assign oxidation numbers in a reaction.

<u>II. Scientific Inquiry Skills Standards</u>

Scientific literacy can be achieved by supporting students to inquire about chemical phenomena. Engaging students in scientific inquiry allows them to develop conceptual understandings and scientific skills that are necessary to be informed decision-makers. The science curriculum should include substantial hands-on laboratory and field experiences, as appropriate, for students to develop and use these skills in a Chemistry course.

SIS1. Make observations, raise questions, and formulate hypotheses.
Students will be able to:
- Observe the world around them from a scientific perspective.
- Pose questions and form hypotheses based on personal observations, scientific articles, experiments, and knowledge.
- Read, interpret, and examine the credibility and validity of scientific claims in different sources of information, such as scientific articles, advertisements, or media stories.

SIS2. Design and conduct scientific investigations.
Students will be able to:
- Articulate and explain the major concepts being investigated and the purpose of an investigation.
- Select required materials, equipment, and conditions for conducting an experiment.
- Identify independent and dependent variables.
- Write procedures that are clear and replicable.
- Employ appropriate methods for accurately and consistently
    - making observations;

  - making and recording measurements at an appropriate level of precision and;
  - collecting data or evidence in an organized way.
- Properly use instruments, equipment, and materials (such as scales, probeware, meter sticks, microscopes, computers, etc.) including: set-up, calibration (if required), technique, maintenance, and storage.
- Follow safety guidelines.

SIS3. Analyze and interpret results of scientific investigations.
Students will be able to:

- Present relationships between variables in appropriate forms.
  - Represent data and relationships between variables in charts and graphs.
  - Use appropriate technology (such as graphing software, etc.) and other tools.
- Use mathematical operations to analyze and interpret data results.
- Identify reasons for inconsistent results, such as sources of error or uncontrolled conditions, and assess the reliability of data.
- Use results of an experiment to develop a conclusion to an investigation that addresses the initial questions and supports or refutes the stated hypothesis.
- State questions raised by an experiment that may require further investigation.

SIS4. Communicate and apply the results of scientific investigations.
Students will be able to:

- Develop descriptions and explanations of scientific concepts that an investigation focused on.
- Review information, explain statistical analysis, and summarize data collected and analyzed from an investigation.
- Explain diagrams and charts that represent relationships of variables.
- Construct a reasoned argument and respond appropriately to critical comments and questions.
- Use language and vocabulary appropriately, speak clearly and logically, and use appropriate technology (such as presentation software, etc.) and other tools to present findings.
- Use and refine scientific models that simulate physical processes or phenomena.

III. Mathematical Skills

Students are expected to know the content of the *Massachusetts Mathematics Curriculum Framework, November 2000* through Grade 8. Below are some specific skills from the *Mathematics Framework* that students in this course should have the opportunity to apply:

- ✓ Construct and use tables and graphs to interpret data sets.
- ✓ Solve simple algebraic expressions.
- ✓ Perform basic statistical procedures to analyze the center and spread of data.
- ✓ Measure with accuracy and precision (length, volume, mass, temperature, time, etc.)
- ✓ Convert within a unit (such as, centimeters to meters).

- ✓ Use common prefixes such as milli-, centi-, and kilo-.
- ✓ Use scientific notation, where appropriate.
- ✓ Use ratio and proportion in the solution of problems.

The following skills are not detailed in the *Mathematics Framework*, but are necessary for a solid understanding in this course:

- ✓ Determine the correct number of significant figures.
- ✓ Determine percent error from experimental and accepted values.
- ✓ Use appropriate metric/standard international (SI) units of measurement for mass (kg); length (m); and time (s).
- ✓ Use Celsius and Kelvin scales.

Introductory Physics High School Standards

Learning Standards for a full first-year course

The high school Introductory Physics standards address the following topics: *Motion and Forces; Conservation of Energy and Momentum; Heat and Heat Transfer; Waves; Electromagnetism; and Electromagnetic Radiation*.

In an introductory physics high school course, students recognize the nature and scope of physics, including its relationship to the other sciences. Students learn about basic topics such as motion, forces, energy, heat, waves, electricity, and magnetism. They learn about natural phenomena by using physical laws to calculate quantities such as velocity, acceleration, momentum, and energy.

Students learn about the relationships between motion and forces through Newton's laws of motion. They study the difference between vector and scalar quantities and learn how to solve basic problems involving these quantities. Students learn about the conservation of energy and momentum and how these are applied to everyday situations. They learn about heat and how thermal energy is transferred throughout the different phases of matter. Students extend their knowledge of waves and how they carry energy. Students gain a better understanding of electric current, voltage, and resistance by learning about Ohm's law. They also gain knowledge about the electromagnetic spectrum in terms of wavelength and frequency.

I. Content Standards

1. Motion and Forces

Broad Concept: Newton's laws of motion and gravitation describe and predict the motion of most objects.

1.1 Compare and contrast vector quantities (such as, displacement, velocity, acceleration, force, and linear momentum) and scalar quantities (such as, distance, speed, energy, mass, and work).

1.2 Distinguish between displacement, distance, velocity, speed, and acceleration. Solve problems involving displacement, distance, velocity, speed, and constant acceleration.

1.3 Create and interpret graphs of 1-dimensional motion, such as position vs. time, distance vs. time, speed vs. time, velocity vs. time, and acceleration vs. time where acceleration is constant.

1.4 Interpret and apply Newton's three laws of motion.

1.5 Use a free-body force diagram to show forces acting on a system consisting of a pair of interacting objects. For a diagram with only co-linear forces, determine the net force acting on a system and between the objects.

1.6 Distinguish qualitatively between static and kinetic friction, and describe their effects on the motion of objects.

1.7 Describe Newton's law of universal gravitation in terms of the attraction between two objects, their masses, and the distance between them.
1.8 Describe conceptually the forces involved in circular motion.

2. Conservation of Energy and Momentum
Broad Concept: The laws of conservation of energy and momentum provide alternate approaches to predict and describe the movement of objects.
2.1 Interpret and provide examples that illustrate the law of conservation of energy.
2.2 Interpret and provide examples of how energy can be converted from gravitational potential energy to kinetic energy and vice versa.
2.3 Describe both qualitatively and quantitatively how work can be expressed as a change in mechanical energy.
2.4 Describe both qualitatively and quantitatively the concept of power as work done per unit time.
2.5 Interpret and provide examples that linear momentum is the product of mass and velocity and is always conserved (law of conservation of momentum). Calculate the momentum of an object.

3. Heat and Heat Transfer
Broad Concept: Heat is energy that is transferred between objects or regions that are at different temperatures by the processes of convection, conduction, and radiation.
3.1 Explain how heat energy is transferred by convection, conduction, and/or radiation.
3.2 Explain how heat energy will move from a higher temperature to a lower temperature until equilibrium is reached.
3.3 Describe the relationship between average molecular kinetic energy and temperature. Recognize that energy is absorbed when a substance changes from a solid to a liquid to a gas, and that energy is released when a substance changes from a gas to a liquid to a solid. Explain the relationships between evaporation, condensation, cooling, and warming.
3.4 Explain the relationship among temperature change in a substance for a given amount of heat transferred, the amount (mass) of the substance, and the specific heat of the substance.

4. Waves
Broad Concept: Waves carry energy from place to place without the transfer of matter.
4.1 Describe the measurable properties of waves (velocity, frequency, wavelength, amplitude, and period) and explain the relationships among them. Recognize examples of simple harmonic motion.
4.2 Distinguish between mechanical and electromagnetic waves.
4.3 Distinguish between the two types of mechanical waves, transverse and longitudinal.
4.4 Describe qualitatively the basic principles of reflection and refraction of waves.
4.5 Recognize that mechanical waves generally move faster through a solid than through a liquid and faster through a liquid than through a gas.
4.6 Describe the apparent change in frequency of waves due to the motion of a source or a receiver (the Doppler effect).

5. Electromagnetism

Broad Concept: Stationary and moving charged particles result in the phenomena known as electricity and magnetism.

5.1 Recognize that an electric charge tends to be static on insulators and can move on and in conductors, and explain that energy can produce a separation of charges.

5.2 Develop a qualitative and quantitative understanding of current, voltage, resistance, and the connection between them (Ohm's law).

5.3 Analyze simple arrangements of electrical components in both serial and parallel circuits. Recognize symbols and understand the functions of common circuit elements (battery, connecting wire, switch, fuse, and resistance) in a schematic diagram.

5.4 Describe conceptually the attractive or repulsive forces between objects relative to their charges and the distance between them (Coulomb's law).

5.5 Explain how electric current is a flow of charge caused by a potential difference (voltage) and how power is equal to current multiplied by voltage.

5.6 Recognize that moving electric charges produce magnetic forces and moving magnets produce electric forces. Recognize that the interplay of electric and magnetic forces is the basis for electric motors, generators, and other technologies.

6. Electromagnetic Radiation

Broad Concept: Oscillating electric or magnetic fields can generate electromagnetic waves over a wide spectrum.

6.1 Recognize that electromagnetic waves are transverse waves and travel at the speed of light through a vacuum.

6.2 Describe the electromagnetic spectrum in terms of frequency and wavelength and identify the location of radio waves, microwaves, infrared radiation, visible light (red, orange, yellow, green, blue, indigo, and violet), ultraviolet rays, x-rays, and gamma rays on the spectrum.

II. Scientific Inquiry Skills Standards

Scientific literacy can be achieved by supporting students to inquire about the physical world. Engaging students in scientific inquiry allows them to develop conceptual understandings and scientific skills that are necessary to be informed decision-makers. The science curriculum should include substantial hands-on laboratory and field experiences, as appropriate, for students to develop and use these skills in an Introductory Physics course.

SIS1. Make observations, raise questions, and formulate hypotheses.

Students will be able to:

- Observe the world around them from a scientific perspective.
- Pose questions and form hypotheses based on personal observations, scientific articles, experiments, and knowledge.
- Read, interpret, and examine the credibility and validity of scientific claims in different sources of information, such as scientific articles, advertisements, or media stories.

SIS2. Design and conduct scientific investigations.

Students will be able to:
- Articulate and explain the major concepts being investigated and the purpose of an investigation.
- Select required materials, equipment, and conditions for conducting an experiment.
- Identify independent and dependent variables.
- Write procedures that are clear and replicable.
- Employ appropriate methods for accurately and consistently
  - making observations;
  - making and recording measurements at an appropriate level of precision and;
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- Properly use instruments, equipment, and materials (such as scales, probeware, meter sticks, microscopes, computers, etc.) including: set-up, calibration (if required), technique, maintenance, and storage.
- Follow safety guidelines.

SIS3. Analyze and interpret results of scientific investigations.
Students will be able to:
- Present relationships between variables in appropriate forms.
  - Represent data and relationships between variables in charts and graphs.
  - Use appropriate technology (such as graphing software, etc.) and other tools.
- Use mathematical operations to analyze and interpret data results.
- Identify reasons for inconsistent results, such as sources of error or uncontrolled conditions, and assess the reliability of data.
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SIS4. Communicate and apply the results of scientific investigations.
Students will be able to:
- Develop descriptions and explanations of scientific concepts that an investigation focused on.
- Review information, explain statistical analysis, and summarize data collected and analyzed from an investigation.
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- Construct a reasoned argument and respond appropriately to critical comments and questions.
- Use language and vocabulary appropriately, speak clearly and logically, and use appropriate technology (such as presentation software, etc.) and other tools to present findings.
- Use and refine scientific models that simulate physical processes or phenomena.

III. Mathematical Skills

Students are expected to know the content of the *Massachusetts Mathematics Curriculum Framework, November 2000* through Grade 8. Below are some specific skills from the *Mathematics Framework* that students in this course should have the opportunity to apply:

- ✓ Construct and use tables and graphs to interpret data sets.
- ✓ Solve simple algebraic expressions.
- ✓ Perform basic statistical procedures to analyze the center and spread of data.
- ✓ Measure with accuracy and precision (length, volume, mass, temperature, time, etc.)
- ✓ Convert within a unit (such as, centimeters to meters).
- ✓ Use common prefixes such as milli-, centi-, and kilo-.
- ✓ Use scientific notation, where appropriate.
- ✓ Use ratio and proportion in the solution of problems.

The following skills are not detailed in the *Mathematics Framework*, but are necessary for a solid understanding in this course:

- ✓ Determine the correct number of significant figures.
- ✓ Determine percent error from experimental and accepted values.
- ✓ Use appropriate metric/standard international (SI) units of measurement for mass (kg); length (m); time (s); force (N); speed (m/s); acceleration ($m \bullet s^{-2}$); frequency (Hz); work and energy (J); power (W); momentum (kg•m/s); electric current (A); electric potential difference/voltage (V); and electric resistance (Ω).
- ✓ Use Celsius and Kelvin scales.

Technology/Engineering High School Standards

Learning Standards for a full first-year course

At the high school level, the topics addressed in the standards include *Engineering Design*; *Construction Technologies*; *Energy and Power Technologies in Fluid, Thermal, and Electrical Systems*; *Communication Technologies*; *and Manufacturing Technologies*.

Students develop the ability to solve problems in technology/engineering using mathematical and scientific concepts. High school students are able to relate the concepts and principles they have learned in science with the knowledge gained in the study of technology/engineering. For example, a well-rounded understanding of energy and power equips students to tackle such issues as the ongoing problems associated with energy supply and energy conservation.

In this course, students pursue engineering questions and technological solutions that emphasize research and problem solving. They achieve a more advanced level of skill in engineering design by learning how to conceptualize a problem, design and build prototypes or models, test their prototypes or models, and make modifications as necessary. Throughout the process of engineering design, students are able to work safely with hand and/or power tools, various materials and equipment, and other resources.

I. Content Standards

1. Engineering Design

Broad Concept: Engineering design involves practical problem solving, research, development, and invention/innovation and requires designing, drawing, building, testing, and redesigning. Students should demonstrate the ability to use the engineering design process to solve a problem or meet a challenge.

1.1 Identify and explain the steps of the engineering design process. The design process steps are identify the problem; research the problem; develop possible solutions; select the best possible solution(s); construct prototypes and/or models; test and evaluate; communicate the solutions; and redesign.

1.2 Understand that the engineering design process is used in the solution of problems and the advancement of society. Identify and explain examples of technologies, objects, and processes that have been modified to advance society.

1.3 Produce and analyze multi-view drawings (orthographic projections) and pictorial (isometric, oblique, perspective) drawings using various techniques.

1.4 Interpret and apply scale and proportion to orthographic projections and pictorial drawings, such as, ¼” = 1’0”, 1 cm = 1 m.

1.5 Interpret plans, diagrams, and working drawings in the construction of prototypes or models.

2. Construction Technologies

Broad Concept: The construction process is a series of actions completed to build a structure including: preparing a site, setting a foundation, erecting a structure, installing utilities, and finishing a site. Various materials, processes, and systems are used to build structures. Students should demonstrate and apply the concepts of construction technology through building and constructing either full-size models or scale models using various materials commonly used in construction. Students should demonstrate the ability to use the engineering design process to solve a problem or meet a challenge in construction technologies.

2.1 Identify and explain the engineering properties of materials used in structures, such as, elasticity, plasticity, R value, density, and strength.
2.2 Distinguish among tension, compression, shear, and torsion, and explain how they relate to the selection of materials in structures.
2.3 Explain Bernoulli's principle and its effect on structures, such as buildings and bridges.
2.4 Calculate the resultant force(s) for a combination of live loads and dead loads.
2.5 Identify and demonstrate the safe and proper use of common hand tools and/or power tools and measurement devices used in construction.
2.6 Recognize the purpose of zoning laws and building codes in the design and use of structures.

3. Energy and Power Technologies–Fluid Systems

Broad Concept: Fluid systems are made up of liquids or gases and allow force to be transferred from one location to another. They also provide water, gas, and oil, and remove waste. They can be moving or stationary and have associated pressures and velocities. Students should demonstrate the ability to use the engineering design process to solve a problem or meet a challenge in fluid systems.

3.1 Explain the basic differences between open (such as, irrigation, forced hot air system, air compressors) and closed (such as, forced hot water system, hydraulic brakes) fluid systems.
3.2 Explain the differences and similarities between hydraulic and pneumatic systems and how each relates to manufacturing and transportation systems.
3.3 Calculate and describe the ability of a hydraulic system to multiply distance, multiply force, and effect directional change.
3.4 Recognize that the velocity of a liquid varies inversely with changes in cross-sectional area along the path of a moving liquid in a pipe.
3.5 Identify and explain sources of resistance (such as, 45º elbow, 90º elbow, and changes in diameter) for water moving through a pipe.

4. Energy and Power Technologies–Thermal Systems

Broad Concept: Thermal systems involve transfer of energy through conduction, convection, and radiation, and are used to control the environment. Students should demonstrate the ability to use the engineering design process to solve a problem or meet a challenge in thermal systems.

4.1 Differentiate among conduction, convection, and radiation in a thermal system, such as, heating and cooling a house and cooking.

4.2 Give examples of how conduction, convection, and radiation are considered in the selection of materials for buildings and in the design of a heating system.
4.3 Explain how environmental conditions such as wind, solar angle, and temperature influence the design of buildings.
4.4 Identify and explain alternatives to nonrenewable energies, such as wind and solar energy conversion systems.

5. Energy and Power Technologies–Electrical Systems
Broad Concept: Electrical systems generate, transfer, and distribute electricity. Students should demonstrate the ability to use the engineering design process to solve a problem or meet a challenge in electrical systems.
5.1 Explain how to measure and calculate voltage, current, resistance, and power consumption in a series circuit and in a parallel circuit. Identify the instruments used to measure voltage, current, power consumption, and resistance.
5.2 Identify and explain the components of a circuit including sources, conductors, circuit breakers, fuses, controllers, and loads. Examples of some controllers are switches, relays, diodes, and variable resistors.
5.3 Explain the relationship between voltage, current, and resistance in a simple circuit using Ohm's law.
5.4 Recognize that resistance is affected by external factors, such as temperature.
5.5 Compare and contrast alternating current (AC) and direct current (DC) and give examples of each.

6. Communication Technologies
Broad Concept: The application of technical processes to exchange information includes symbols, measurements, icons, and graphic images. Students should demonstrate the ability to use the engineering design process to solve a problem or meet a challenge in communication technologies.
6.1 Explain how information travels through the following media: electrical wire, optical fiber, air, and space.
6.2 Differentiate between digital and analog signals. Describe how communication devices employ digital and analog technologies, such as, computers and cell phones.
6.3 Explain how the various components and processes of a communication system function. The components are source, encoder, transmitter, receiver, decoder, destination, storage, and retrieval.
6.4 Identify and explain the applications of laser and fiber optic technologies (such as, telephone systems, cable television, and photography).
6.5 Explain the application of electromagnetic signals in fiber optic technologies, and include critical angle and total internal reflection.

7. Manufacturing Technologies
Broad Concept: Manufacturing processes can be classified into six groups: casting and molding, forming, separating, conditioning, assembling, and finishing. Students should demonstrate the ability to use the engineering design process to solve a problem or meet a challenge in manufacturing technologies.

7.1 Describe the manufacturing processes of casting and molding, forming, separating, conditioning, assembling, and finishing.
7.2 Identify the criteria necessary to select the tools and procedures used in the safe production of products in the manufacturing process, such as material properties, required tolerances, and end-uses.
7.3 Describe the advantages of using robotics in the automation of manufacturing processes, such as, increased production, improved quality, and safety.

II. Steps of the Engineering Design Process

Students should be provided opportunities for hands-on experiences to design, build, test and evaluate (and redesign, if necessary) a prototype or model of their solution to a problem. Students should have access to materials, hand and/or power tools, and resources needed to engage in these tasks. Students may also engage in design challenges that provide constraints and specifications students must consider as they develop a solution.

Steps of the Design Process*

1. Identify the need or problem
2. Research the need or problem
   - Examine current state of the issue and current solutions
   - Explore other options via the Internet, library, interviews, etc.
3. Develop possible solution(s)
   - Brainstorm possible solutions
   - Draw on mathematics and science
   - Articulate the possible solutions in two and three dimensions
   - Refine the possible solutions
4. Select the best possible solution(s)
   - Determine which solution(s) best meet(s) the original requirements
5. Construct one or more prototypes and/or models
   - Model the selected solution(s) in two and three dimensions
6. Test and evaluate the solution(s)
   - Does it work?
   - Does it meet the original design constraints?
7. Communicate the solution(s)
   - Make an engineering presentation that includes a discussion of how the solution(s) best meet(s) the needs of the initial problem, opportunity, or need
   - Discuss societal impact and tradeoffs of the solution(s)
8. Redesign
   - Modify the solution(s) based on information gathered during the tests and presentation

**The engineering design process is listed under the first content standard in the course, title: Engineering Design.*

III. Mathematical Skills

Students are expected to know the content of the *Massachusetts Mathematics Curriculum Framework, November 2000* through Grade 8. Below are some specific skills from the *Mathematics Framework* that students in this course should have the opportunity to apply:

- ✓ Construct and use tables and graphs to interpret data sets.
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- ✓ Use both metric/standard international (SI) and U.S. Customary (English) systems.
- ✓ Convert within a unit (such as, centimeters to meters and inches to feet).
- ✓ Use common prefixes such as milli-, centi-, and kilo-.
- ✓ Use scientific notation, where appropriate.
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- ✓ Use Celsius and Fahrenheit scales.