Westhill Institute, SC
Vestigia Nulla Retrorsum

Science and Technology Curriculum Framework

(Based upon the Massachusetts Academic Content Standards)

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Full Implementation Scheduled for June 2012

Purpose and Nature of Science and Technology/Engineering

The Purpose of Science and Technology/Engineering Education

Investigations in science and technology/engineering involve a range of skills, habits of mind, and subject matter knowledge. The purpose of science and technology/engineering education in Massachusetts is to enable students to draw on these skills and habits, as well as on their subject matter knowledge, in order to participate productively in the intellectual and civic life of American society and to provide the foundation for their further education in these areas if they seek it.

The Nature of Science

Science may be described as the attempt to give good accounts of the patterns in nature. The result of scientific investigation is an understanding of natural processes. Scientific explanations are always subject to change in the face of new evidence. Ideas with the most durable explanatory power become established theories or are codified as laws of nature. Overall, the key criterion of science is that it provide a clear, rational, and succinct account of a pattern in nature. This account must be based on data gathering and analysis and other evidence obtained through direct observations or experiments, reflect inferences that are broadly shared and communicated, and be accompanied by a model that offers a naturalistic explanation expressed in conceptual, mathematical, and/or mechanical terms. Here are some everyday examples of patterns seen in nature:

- The sun appears to move each day from the eastern horizon to the western horizon.
- Virtually all objects released near the surface of the earth sooner or later fall to the ground.
- Parents and their offspring are similar, e.g., lobsters produce lobsters, not cats.
- Green is the predominant color of most plants.
- Some objects float while others sink.
- Fire yields heat.
- Weather in North America generally moves from west to east.
- Many organisms that once inhabited the earth no longer do so.

It is beyond the scope of this document to examine the scientific accounts of these patterns. Some are well known, such as that the rotation of the earth on its axis gives rise to the apparent travel of the sun across the sky, or that fire is a transfer of energy from one form to another. Others, like buoyancy or the cause of extinction, require subtle and sometimes complex accounts. These patterns, and many others, are the puzzles that scientists attempt to explain.

The Nature of Technology/Engineering

Technology/engineering seeks different ends from those of science. Engineering strives to design and manufacture useful devices or materials, defined as technologies, whose purpose is to increase our efficacy in the world and/or our enjoyment of it. Can openers are technology, as are microwave ovens, microchips, steam engines, camcorders, safety glass, zippers, polyurethane, the Golden Gate Bridge, much of Disney World, and the "Big Dig" in

Boston. Each of these, with innumerable other examples, emerges from the scientific knowledge, imagination, persistence, talent, and ingenuity of practitioners of technology/engineering. Each technology represents a designed solution, usually created in response to a specific practical problem, that applies scientific principles. As with science, direct engagement with the problem is central to defining and solving it.

The Relationship Between Science and Technology/Engineering

In spite of their different goals, science and technology have become closely, even inextricably, related in many fields. The instruments that scientists use, such as the microscope, balance, and chronometer, result from the application of technology/engineering. Scientific ideas, such as the laws of motion, the relationship between electricity and magnetism, the atomic model, and the model of DNA, have contributed to achievements in technology and engineering, such as improvement of the internal combustion engine, power transformers, nuclear power, and human gene therapy. The boundaries between science and technology/engineering blur together to extend knowledge.

Inquiry, Experimentation, and Design in the Classroom

Inquiry-Based Instruction

Engaging students in inquiry-based instruction is one way of developing conceptual understanding, content knowledge, and scientific skills. Scientific inquiry as a means to understand the natural and human-made worlds requires the application of content knowledge through the use of scientific skills. Students should have curricular opportunities to learn about and understand science and technology/engineering through participatory activities, particularly laboratory, fieldwork, and design challenges.

Inquiry, experimentation, and design should not be taught or tested as separate, stand-alone skills. Rather, opportunities for inquiry, experimentation, and design should arise within a well-planned curriculum. Instruction and assessment should include examples drawn from life science, physical science, earth and space science, and technology/engineering standards. Doing so will make clear to students that *what* is known does not stand separate from *how* it is known.

Asking Questions

Asking questions and pursuing answers are keys to learning in all academic disciplines. In the science classroom, one way students can do this is by exploring scientific phenomena in a classroom laboratory or an investigation around the school. Investigation and experimentation build essential scientific skills such as observing, measuring, replicating experiments, manipulating equipment, and collecting and reporting data. Students may choose what phenomenon to study or conduct investigations and experiments that are selected and guided by the teacher.

Students can also examine questions pursued by scientists in previous investigations of natural phenomena and processes, as reported or shown in textbooks, papers, videos, the Internet, and other media. These sources are valuable because they efficiently organize and highlight key concepts and supporting evidence that characterize the most important work in science. Such study can then be supported in the classroom by demonstrations, experiments, or simulations that deliberately manage features of a natural object or process. Whatever the instructional approach, science instruction should include both concrete and manipulable materials, along with explanatory diagrams and texts.

Investigations

An inquiry-based approach to science education also engages students in hands-on investigations that allow them to draw upon their prior knowledge and build new understandings and skills. Hands-on experiences should always be purposeful activities that are consistent with current research on how people learn and that develop student understanding of science concepts. Students should also have multiple opportunities to share, present, review, and critique scientific information or findings with others.

The characteristics of investigations develop through the different grade spans:

- **In grades PreK–2**, scientific investigations can center on student questions, observations, and communication about what they observe. For example, students might plant a bean seed following simple directions written on a chart. Then they can write down what happens over time in their own words.

- **In grades 3–5**, students can plan and carry out investigations as a class, in small groups, or independently, often over a period of several class lessons. The teacher should first model the process of selecting a question that can be answered, formulating a hypothesis, planning the steps of an experiment, and determining the most objective way to test the hypothesis. Students should incorporate mathematical skills of measuring and graphing to communicate their findings.

- **In grades 6–8**, teacher guidance remains important but allows for more variation in student approach. Students at this level are ready to formalize their understanding of what an experiment requires by controlling variables to ensure a fair test. Their work becomes more quantitative, and they learn the importance of carrying out several measurements to minimize sources of error. Because students at this level use a greater range of tools and equipment, they must learn safe laboratory practices (see Appendix IV). At the conclusion of their investigations, students in these grades can be expected to prepare reports of their questions, procedures, and conclusions.

- **In high school**, students develop greater independence in designing and carrying out experiments, most often working alone or in small groups. They come up with questions and hypotheses that build on what they have learned from secondary sources. They learn to critique and defend their findings, and to revise their explanations of phenomena as new findings emerge. Their facility with using a variety of physical and conceptual models increases. Students in the final two years of high school can be encouraged to carry out extended independent experiments that explore a scientific hypothesis in depth, sometimes with the assistance of a scientific mentor from outside the school setting.

  Preparation for post-secondary opportunities is another reason to provide regular laboratory and fieldwork experiences in high school science and technology/engineering courses. The Massachusetts Board of Higher Education's *Admissions Standards for the Massachusetts State Colleges and University* (www.mass.edu\a_f) 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. All high school courses based on the standards presented in this document should 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.

The Engineering Design Process

Just as inquiry and experimentation guide investigations in science, the Engineering Design Process guides solutions to technology/engineering design challenges. Learning technology/engineering content and skills is greatly enhanced by a hands-on, active approach that allows students to engage in design challenges and safely work with materials to model and test solutions to a problem. Using the steps of the Engineering Design Process, students can solve technology/engineering problems and apply scientific concepts across a wide variety of topics to develop conceptual understanding. The specific steps of the Engineering Design Process are included in the Technology/Engineering strand, on page 84 of this *Framework*.

Skills of Inquiry, Experimentation, and Design

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. To achieve this, students need to develop skills that allow them to search out, describe, and explain natural phenomena and designed artifacts. Scientific inquiry, experimentation, and design involve practice (skills) in direct relationship to knowledge; content knowledge *and* skills are necessary to inquire about the natural and human-made worlds.

The skills for grades PreK–8 listed below are unchanged from those presented in the 2001 *Framework*. The new Scientific Inquiry Skills standards listed for high school reflect essential elements of scientific practice and should be integrated into curriculum along with content standards.

High School

This *Framework* introduces four **Scientific Inquiry Skills** (SIS) standards that are included in each introductory high school course (except Technology/Engineering, where they are replaced by the steps of the Engineering Design Process):

- 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.

In each course, each Scientific Inquiry Skills standard includes an example skill set that further defines and articulates the standard.

Also new to the 2006 *Framework* are the lists of **mathematical skills** needed for a solid understanding of each high school science and technology/engineering course. Engaging in science and technology/engineering often involves the use of mathematics to analyze and support findings of investigations or the design process. Most mathematical skills listed are based on grade-appropriate standards outlined in the *Massachusetts Mathematics Curriculum Framework.* Any specialized mathematical skills not detailed in the *Mathematics Framework* are listed separately. Please note that these lists are provided only as examples and are not exhaustive; the lists do not represent all mathematical skills students might need in a typical course.

Guiding Principles

The following Guiding Principles present a set of tenets about effective PreK–12 science and technology/engineering programs. The goal of the Guiding Principles is to help educators create inquiry-based educational environments that encourage student curiosity, engagement, persistence, respect for evidence, and sense of responsibility.

GUIDING PRINCIPLE I

A comprehensive science and technology/engineering education program enrolls all students from PreK through grade 12.

Students benefit from studying science and technology/engineering throughout all their years of schooling. They should learn the fundamental concepts of each domain of science, as well as the connections across those domains and to technology/engineering. This *Framework* will assist educators in developing science and technology/engineering programs that engage all students.

All students in grades PreK–5 should have science instruction on a regular basis every year. Approximately one-quarter of PreK–5 science time should be devoted to technology/ engineering.

In grades 6–8, students should have a full year of science study every year. Students in grades 6–8 should have one year of technology/engineering education in addition to their three years of science. Schools may choose to offer technology/engineering as a semester course in each of two years; as a full-year course in grade 8; or in three units, one each year in grades 6, 7, and 8.

In grades 9 and 10, all students should have full-year laboratory-based science and technology/engineering courses. In grades 11 and 12, students should take additional science and technology/engineering courses or pursue advanced study through advanced placement courses, independent research, or study of special topics.

GUIDING PRINCIPLE II

An effective science and technology/engineering program builds students' understanding of the fundamental concepts of each domain of science, and their understanding of the connections across these domains and to basic concepts in technology/engineering.

Each domain of science has its particular approach and area of focus. However, students need to understand that much of the scientific work done in the world draws on multiple disciplines. Oceanographers, for instance, use their knowledge of physics, chemistry, biology, earth science, and technology to chart the course of ocean currents. Connecting the domains of natural science with mathematical study and with one another, and to practical applications through technology and engineering, should be one goal of science education.

In the elementary grades, coursework should integrate all of the major domains of science and technology/engineering every year. In one approach, instruction can be organized around distinct but complementary units drawn from the earth, life, and physical sciences and from technology/engineering. In another approach, teachers working together and with outside help (e.g., museum personnel, scientists, or engineers) can organize activities around concepts or topics unifying all of the domains.

At the middle and high school levels, science faculty may choose either a discipline-based or an integrated approach in science. In choosing an approach, faculty will want to consider the particular content expertise of teachers and the academic goals, abilities, and interests of students. In this document, the high school standards are written to allow for choice in course organization and sequence.

Guiding Principle III

Science and technology/engineering are integrally related to mathematics.

Mathematics is an essential tool for scientists and engineers because it specifies in precise and abstract (general) terms many attributes of natural phenomena and manmade objects and the nature of relationships among them. Mathematics facilitates precise analysis and prediction.

Take, for example, the equation for one of Newton's Laws: F = ma (force equals mass times acceleration). This remarkably succinct description states the invariable relationship among three fundamental features of our known universe. Its mathematical form permits all kinds of analyses and predictions.

Other insights come from simple geometric analysis applied to the living world. For example, volume increases by the cube of an object's fundamental dimension while area increases by the square. Thus, in an effort to maintain constant body temperature, most small mammals metabolize at much higher rates than larger ones. It is hard to imagine a more compelling and simple explanation than this for the relatively high heart rate of rodents versus antelopes.

Even simpler is the quantification of dimensions. How small is a bacterium, how large is a star, how dense is lead, how fast is sound, how hard is a diamond, how sturdy is the bridge, how safe is the plane? These questions can all be answered mathematically. And with these analyses, all kinds of intellectual and practical questions can be posed and solved.

Teachers, curriculum coordinators, and others who help implement this *Framework* must be aware of the level of mathematical knowledge needed for each science and technology/ engineering course, especially at the high school level, and must ensure that the appropriate mathematical knowledge has already been taught or is being taught concurrently.

Guiding Principle IV

An effective program in science and technology/engineering addresses students' prior knowledge and misconceptions.

Students are innately curious about the world and wonder how things work. They may make spontaneous, perceptive observations about natural objects and processes, and can often be found taking things apart and reassembling them. In many cases, they have developed mental models about how the world works. However, these mental models may be inaccurate, even though they make sense to the students, and inaccuracies work against learning.

Research into misconceptions demonstrates that children can hold onto misconceptions even while reproducing what they have been taught are the "correct answers." For example, young children may repeat that the earth is round, as they have been told, while continuing to believe that the earth is flat, which is what they can see for themselves. They may find a variety of ingenious ways to reconcile their misconception with the correct knowledge, e.g., by concluding that we live on a flat plate inside the round globe.

Teachers must be skilled at uncovering inaccuracies in students' prior knowledge and observations, and in devising experiences that will challenge inaccurate beliefs and redirect student learning along more productive routes. The students' natural curiosity provides one entry point for learning experiences designed to remove students' misconceptions in science and technology/engineering.

GUIDING PRINCIPLE V

Investigation, experimentation, and problem solving are central to science and technology/engineering education.

Investigations introduce students to the nature of original research, increase students' understanding of scientific and technological concepts, promote skill development, and provide entry points for all learners. Teachers should establish the learning goals and contexts for investigations, experiments, and laboratories; guide student activities; and help students focus on important ideas and concepts. Lessons should be designed so that knowledge and skills are developed and used together (also see *Inquiry, Experimentation, and Design in the Classroom*, pages 9–12).

Puzzlement and uncertainty are common features in experimentation. Students need time to examine their ideas as they apply them in explaining a natural phenomenon or solving a design problem. Opportunities for students to reflect on their own ideas, collect evidence, make inferences and predictions, and discuss their findings are all crucial to growth in understanding.

Students should also have opportunities in the classroom to replicate important experiments that have led to well-confirmed knowledge about the natural world, e.g., Archimedes' principle and the electric light bulb. By examining the thinking of experts, students can learn to improve their own problem-solving efforts.

GUIDING PRINCIPLE VI

An effective science and technology/engineering program builds upon and develops students' literacy skills and knowledge.

Reading, writing, and communication skills are necessary elements of learning and engaging in science and technology/engineering. Teachers should consistently support students in acquiring comprehension skills and strategies, as well as vocabulary, to deepen students' understanding of text meaning. Science and technology/engineering texts contain specialized knowledge that is organized in a specific way. For example, scientific texts will often articulate a general principle that describes a pattern in nature, followed by evidence that supports and illustrates the principle. Science and technology/engineering classrooms make use of a variety of text materials, including textbooks, journals, lab instructions, and reports. Texts are generally informational in nature, rather than narrative, and often include high proportions of facts and terms related to a particular phenomenon, process, or structure. Teachers should help students understand that the types of texts students read, along with the purpose(s) for reading these texts, are specific to science and technology/engineering. Supporting the development of students' literacy skills will help them to deepen their understanding of science and technology/engineering concepts.

Students should be able to use reading, writing, and communication skills to enhance their understanding of scientific and technological/engineering text materials, including informational text, diagrams, charts, graphs, and formulas; communicate ideas; and apply logic and reasoning in scientific and technological/engineering contexts. Students should be able to use a variety of texts to distinguish fact from opinion, make inferences, draw conclusions, and collect evidence to test hypotheses and build arguments. Successful development of these skills requires explicit opportunities to develop literacy skills and knowledge.

GUIDING PRINCIPLE VII

Students learn best in an environment that conveys high academic expectations for all students.

A high quality education system simultaneously serves the goals of equity and excellence. At every level of the education system, teachers should act on the belief that young people from every background can learn rigorous science content and solve tough engineering problems. Teachers and guidance personnel should advise students and parents that rigorous courses and advanced sequences in science and technology/engineering will prepare them for success in college and the workplace. After-school, weekend, and summer enrichment programs offered by school districts or communities may be especially valuable and should be open to all. Schools and districts should also invite role models from business and the community (including professional engineers and scientists) to visit classes, work with students, and contribute to instruction.

Regardless of whether students go on to an institute of higher education or to a workplace, they should be equipped with the skills and habits required for postsecondary success. Skills such as the ability to work through difficult problems, to be creative in problem solving, and to think critically and analytically will serve students in any setting. When students work toward high expectations in these areas, they develop the foundation they need for success after graduation.

GUIDING PRINCIPLE VIII

Assessment in science and technology/engineering serves to inform student learning, guide instruction, and evaluate student progress.

Assessment reflects classroom expectations and shows outcomes of student learning based on established knowledge and performance goals. The learning standards in this *Framework* are a key resource for setting such knowledge and performance objectives in science and technology/engineering. Assessment assists teachers in improving classroom practice, planning curricula, developing self-directed learners, reporting student progress, and evaluating programs. It provides students with information about how their knowledge and skills are developing and what can be done to improve them. It lets parents know how well their children are doing and what needs to be done to help them do better.

Using assessment data, teachers can better meet the needs of individual students as those students work toward mastery of the *Framework* learning standards. Teachers should assess student progress toward desired outcomes on a regular basis through formative assessments. Formative assessments allow a teacher to benchmark progress, evaluate the pace of instruction, and determine the need for intervention support. Through formative assessments, students receive timely feedback regarding their accomplishments and needs.

Diagnostic information gained from multiple forms of assessment enables teachers to adjust their day-to-day and week-to-week practices to foster greater student achievement. The many types of assessment include paper-and-pencil testing, performance testing, interviews, and portfolios, as well as less formal inventories such as regular observation of student responses to instruction. In helping students achieve standards, assessments should also use a variety of question formats: multiple-choice, short-answer, and open-ended. Performance-based assessments should also be developed that allow students to demonstrate what they have learned in the context of solving a problem or applying a concept. This kind of assessment requires students to refine a problem, devise a strategy to solve it, apply relevant knowledge, conduct sustained work, and deal with both complex concepts and discrete facts.

GUIDING PRINCIPLE IX

An effective program in science and technology/engineering gives students opportunities to collaborate in scientific and technological endeavors and communicate their ideas.

Scientists and engineers work as members of their professional communities. Ideas are tested, modified, extended, and reevaluated by those professional communities over time. Thus, the ability to convey their ideas to others is essential for these advances to occur.

In order to learn how to effectively communicate scientific and technological ideas, students require practice in making written and oral presentations, fielding questions, responding to critiques, and developing replies. Students need opportunities to talk about their work in focused discussions with peers and with those who have more experience and expertise. This communication can occur informally, in the context of an ongoing student collaboration or on-line consultation with a scientist or engineer, or more formally, when a student presents findings from an individual or group investigation.

GUIDING PRINCIPLE X

A coherent science and technology/engineering program requires district-wide planning and on-going support for implementation.

District-Wide Planning

An effective curriculum that addresses the learning standards of this *Framework* must be planned as a PreK–12 cohesive unit. Teachers in different classrooms and at different levels should agree about what is to be taught in given grades. For example, middle school teachers should be able to expect that students coming from different elementary schools within a district share a common set of experiences and understandings in science and technology/engineering, and that the students they send on to high school will be well-prepared for what comes next. In order for this expectation to be met, middle school teachers need to plan curricula in common with their elementary and high school colleagues, and with district staff.

To facilitate planning, the district coordinator should be involved in articulating, coordinating, and implementing a district-wide (PreK–12) science and technology/engineering curriculum. School districts should select engaging, challenging, and accurate curriculum materials that are based on research regarding how children learn science and technology/engineering, and research about how to overcome student misconceptions. To aid their selection, districts may want to consult this *Framework's* Appendix VII, *Criteria for Evaluating Instructional Materials and Programs in Science and Technology/Engineering*.

When planning for the introduction of a new curriculum, it is important to identify explicitly how success will be measured. Indicators need to be determined and should be communicated to all stakeholders. Supervisors should monitor whether the curriculum is actually being used and how instruction has changed. Teacher teams, working across grade levels, should look at student work and other forms of assessment to determine whether there is evidence of achievement of the sought-for gains in student understanding.

On-Going Support

Implementation of a new curriculum is accomplished over multiple years and requires opportunities for extensive professional development. Teachers must have both content knowledge and pedagogical expertise to use curricular materials in a way that enhances student learning. A well-planned program for professional development provides for both content learning and content-based pedagogical training. It is further recommended that middle and high school courses be taught by teachers who are certified in their area, and who are therefore very familiar with the safe use of materials, tools, and processes.

Science and technology/engineering programs can be more effective when families and community members are involved in the selection of curricula and materials, the planning process, and the implementation of the program. Parents who have a chance to examine and work with the materials in the context of a Family Science Night, Technology/ Engineering Fair, or other occasion will better understand and support their children's learning. In addition, local members of the science and engineering community may be able to lend their own expertise to assist with the implementation of curricula. Teachers and administrators should invite scientists, engineers, higher education faculty, representatives of local businesses, and museum personnel to help enrich the curriculum with community connections.

Earth and Space Science / Grade 12

In earth and space science, students study the origin, structure, and physical phenomena of the earth and the universe. Earth and space science studies include concepts in geology, meteorology, oceanography, and astronomy. These studies integrate previously or simultaneously gained understandings in physical and life science with the physical environment. Through the study of earth and space, students learn about the nature and interactions of oceans and the atmosphere, and of earth processes, including plate tectonics, changes in topography over time, and the place of the earth in 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.

  High school learning standards fall under the following four subtopics: *Matter and Energy in the Earth System; Energy Resources in the Earth System; Earth Processes and Cycles;* and *The Origin and Evolution of the Universe.*

Earth and Space Science learning standards are also grouped under Broad Topics in Appendix I, which highlights the relationships of standards among grade spans.

Earth and Space Science, High School

Learning Standards for a Full First-Year Course

I. CONTENT STANDARDS

1. Matter and Energy in the Earth System

Central 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 (e.g., global winds, convection cells, land/sea breezes, 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 (e.g.,

thunderstorms, winter storms [nor'easters], hurricanes, 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

Central Concepts: Energy resources are used to sustain human civilization. The amount and accessibility of these resources influence their use and their impact on the environment.

2.1 Recognize, describe, and compare renewable energy resources (e.g., solar, wind, water, biomass) and nonrenewable energy resources (e.g., fossil fuels, 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

Central 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 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. Earth Processes and Cycles (cont.)

3.4 Explain how water flows into and through a watershed. Explain the roles 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

Central Concepts: 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 (i.e., "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 (e.g., day, year, solar/lunar eclipses, 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 as students inquire about geologic, meteorological, oceanographic, and astronomical phenomena. The 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, including 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, as well as the inquiry skills listed below.

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

- Observe the world 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.

- 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 appropriate levels of precision
  - collecting data or evidence in an organized way
- Properly use instruments, equipment, and materials (e.g., scales, probeware, meter sticks, microscopes, computers) including set-up, calibration (if required), technique, maintenance, and storage.
- Follow safety guidelines.

SIS3. Analyze and interpret results of scientific investigations.

- Present relationships between and among variables in appropriate forms.
- Represent data and relationships between and among variables in charts and graphs.
- Use appropriate technology (e.g., graphing software) and other tools.
- Use mathematical operations to analyze and interpret data results.
- Assess the reliability of data and identify reasons for inconsistent results, such as sources of error or uncontrolled conditions.
- 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.

- Develop descriptions of and explanations for scientific concepts that were a focus of one or more investigations.
- Review information, explain statistical analysis, and summarize data collected and analyzed as the result of 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 (e.g., presentation software) 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*, 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.

Earth and Space Science, High School

Learning Standards for a Full First-Year Course

- ✓ Perform basic statistical procedures to analyze the center and spread of data.
- ✓ Measure with accuracy and precision (e.g., length, volume, mass, temperature, time)
- ✓ Convert within a unit (e.g., centimeters to meters).
- ✓ Use common prefixes such as *milli-*, *centi-*, and *kilo-*.
- ✓ Use scientific notation, where appropriate.
- ✓ Use ratio and proportion to solve 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/s^2); and frequency (Hz).
- ✓ Use the Celsius and Kelvin scales.

WHAT IT LOOKS LIKE IN THE CLASSROOM

Surface Processes and Landscape

Adapted from a contribution from Dan Barstow

Earth and Space Science, High School

In Chelmsford, Mr. D's high school earth science students investigated the interconnections between Earth systems by studying river basins and the geologic materials through which they flow. He began this activity by asking the students, "How do rivers affect their surroundings?" Mr. D instructed the class to write down their thoughts, along with what they know about the geology and plant life of the nearby Merrimack River. The class discussed their thoughts.

Next, the class visited two sites on the Merrimack River to gather geologic and ecological data. Mr. D helped the students identify areas along the river where erosion and deposition occurred. At each site, they observed the velocity of the water and noted where it was moving fast or slow. They collected information about the riverbank, including its slope and composition. Mr. D instructed the students on how to classify vegetation near the bank of the river and estimate its density. The students used a Global Positioning System to identify and record the latitude and longitude of both sites so that they could later pinpoint the exact locations they had observed along the river. Students sketched all their observations and recorded their data.

Upon returning to the classroom, Mr. D asked the students to use their observations and data to draw a bird's-eye view of the sections of the river they observed. After completing their drawings, the students found a satellite image of the Merrimack River on the Internet. Using the Merrimack image, Mr. D helped students relate their birds-eye drawings to the satellite image. Students identified patterns of erosion, degrees of meandering, and surrounding vegetation. They used Web sites, topographical maps, and other resources to collect additional information about the river. They researched how the underlying bedrock, topology, and climate shape and alter the Merrimack.

Mr. D then instructed the students to make comparisons between the Merrimack River and other rivers around the world. Students were grouped into pairs and each pair was assigned a specific river to investigate. Among the rivers researched were the Nile, Amazon, Danube, Tigris, Yangtze, and Mississippi. Each pair of students downloaded a satellite image of its assigned river and annotated the image to highlight features of the river. Students collected information on meandering, vegetation, patterns of erosion, and flood plains from the images as they had done for the Merrimack. One pair noted, for example, that the fertile green vegetated Nile flood plain creates a dramatic contrast with the neighboring dry brown desert. Another pair noted that the Mississippi has many meanderings, ox bow lakes, and other erosional features that have evolved over time. As a class, Mr. D and the students discussed the similarities and differences between the rivers they investigated as pairs and the local Merrimack River.

The class then worked cooperatively to summarize how the characteristics of a river are the result of interactions of materials and processes in the river system. They then articulated ideal locations along a river for the following: (1) white water rafting, (2) setting up a farm, and (3) nearby human habitation. They detailed the optimal bank slope, basin shape, and water velocity for each of the locations.

As a result of this experience, students learned how to make ground-based observations, and to accurately collect and analyze data. Students were also able to read, interpret, and analyze satellite images; describe how rivers cause erosion and create landscapes; and explain how surface processes impact human decisions.

WHAT IT LOOKS LIKE IN THE CLASSROOM

Assessment Strategies

- Students can correctly record data using appropriate language and units in an organized way.
- Students can create individual portfolios of their work, including some of the images they collected/downloaded, data charts, a summary of work completed, and a conclusive report. They can also present and communicate their work to other groups using appropriate technology.
- Students can be shown images they have seen or not seen and be asked to annotate the images and summarize their properties according to a scaled rubric. Possible rubric items for working with images could include the following:
    1. Able to make distinction between water bodies (e.g., rivers, lakes, oceans) and land features (e.g., mountains, cities, plains).
    2. Able to identify detailed features of river basins, including ox bows, river erosion patterns, vegetation, and flood plains.
    3. Able to make connections between the change processes and resulting features (e.g., relating river meanders to land topology).

Earth and Space Science Learning Standards

High School

1.8 Read, interpret, and analyze a combination of ground-based observations, satellite data, and computer models to demonstrate Earth systems and their interconnections.

3.1 Explain how physical and chemical weathering leads to erosion and the formation of soils and sediments, and creates various types of landscapes. Give examples that show the effects of physical and chemical weathering on the environment.

Scientific Inquiry Skills Standards

High School

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

- Observe the world from a scientific perspective.

SIS2. Design and conduct scientific investigations.

- Employ appropriate methods for accurately and consistently
    - making observations
    - making and recording measurements at appropriate levels of precision
    - collecting data or evidence in an organized way

SIS4. Communicate and apply the results of scientific investigations.

- Use language and vocabulary appropriately, speak clearly and logically, and use appropriate technology (e.g., presentation software) and other tools to present findings.

Biology-Grade 10

The life sciences investigate the diversity, complexity, and interconnectedness of life on earth. Students are naturally drawn to examine living things, and as they progress through the grade levels, they become capable of understanding the theories and models that scientists use to explain observations of nature. In this respect, a PreK–12 life science curriculum mirrors the way in which the science of biology has evolved from observation to classification to theory. By high school, students learn the importance of Darwin's theory of evolution as a framework for explaining continuity, diversity, and change over time. Students emerge from an education in the life sciences recognizing that order in natural systems arises in accord with rules that seem to govern the physical world, and can be modeled and predicted through the use of mathematics.

- At the **high school** level, 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. Students in high school study life through cell biology and genetics (molecular level), vertebrate anatomy and physiology (tissue and organ levels), and ecology (organism and population levels).

  Organic evolution, a concept fundamental to understanding modern biology, unifies these diverse topics. 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.

  Learning standards for Biology at the high school level fall under the following six subtopics: *The Chemistry of Life; Cell Biology; Genetics; Anatomy and Physiology; Evolution and Biodiversity;* and *Ecology*.

Life Science learning standards are also grouped under Broad Topics in Appendix I, which highlights the relationships of standards among grade spans.

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 in crimes or exonerate persons wrongly accused, determine paternity, diagnose diseases, make high-yield pest-resistant crops, and treat genetic ailments. Educators should recognize the importance of introducing students to biotechnology as a way of better understanding the molecular basis of heredity. Educators should also provide students with methods and critical thinking skills to evaluate the benefits and risks of this technology.

Biology, High School

Learning Standards for a Full First-Year Course

I. Content Standards

1. The Chemistry of Life
Central 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, and S.
1.2 Describe the basic molecular structures and primary functions of the four major categories of organic molecules (carbohydrates, lipids, proteins, 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, that have an effect on enzymes.

2. Cell Biology
Central Concepts: 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, active transport).
2.2 Compare and contrast, at the cellular level, the general structures and degrees of complexity of prokaryotes and eukaryotes.
2.3 Use cellular evidence (e.g., cell structure, cell number, cell reproduction) and modes of nutrition to describe the 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
Central Concepts: 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 characteristic to 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.

Biology, High School

Learning Standards for a Full First-Year Course

3. Genetics (cont.)

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, codominant, sex-linked, polygenic, incomplete dominance, multiple alleles).

3.5 Describe how Mendel's laws of segregation and independent assortment can be observed through patterns of inheritance (e.g., dihybrid crosses).

3.6 Use a Punnett Square to determine the probabilities for genotype and phenotype combinations in monohybrid crosses.

4. Anatomy and Physiology

Central Concepts: There is a relationship between the organization of cells into tissues and the organization of tissues into organs. The structures and functions 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 among different parts of the body and mediates 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 muscles, bones, cartilage, ligaments, tendons) works with other systems to support the body and allow for movement. Recognize that bones produce 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 among 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.

Biology, High School

Learning Standards for a Full First-Year Course

5. Evolution and Biodiversity

Central Concepts: 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 within a population.

6. Ecology

Central 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, 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.

Biology, High School

Learning Standards for a Full First-Year Course

II. Scientific Inquiry Skills Standards

Scientific literacy can be achieved as students inquire about the biological world. The curriculum should include substantial hands-on laboratory and field experiences, as appropriate, for students to develop and use scientific skills in biology, along with the inquiry skills listed below.

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

Observe the world 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.

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 appropriate levels of precision
- collecting data or evidence in an organized way

Properly use instruments, equipment, and materials (e.g., scales, probeware, meter sticks, microscopes, computers) including set-up, calibration (if required), technique, maintenance, and storage.
Follow safety guidelines.

SIS3. Analyze and interpret results of scientific investigations.

Present relationships between and among variables in appropriate forms.

- Represent data and relationships between and among variables in charts and graphs.
- Use appropriate technology (e.g., graphing software) and other tools.

Use mathematical operations to analyze and interpret data results.
Assess the reliability of data and identify reasons for inconsistent results, such as sources of error or uncontrolled conditions.
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.

Develop descriptions of and explanations for scientific concepts that were a focus of one or more investigations.
Review information, explain statistical analysis, and summarize data collected and analyzed as the result of 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 (e.g., presentation software) 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,* 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 (e.g., length, volume, mass, temperature, time)
- ✓ Convert within a unit (e.g., centimeters to meters).
- ✓ Use common prefixes such as *milli-, centi-,* and *kilo-*.
- ✓ Use scientific notation, where appropriate.
- ✓ Use ratio and proportion to solve 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 the Celsius scale.

What It Looks Like in the Classroom

Exercise Physiology

Biology, High School

While studying anatomy and physiology, Miss Scott helped her high school biology students understand the complex interactions between cells, organs, and organ systems through an investigation of exercise physiology. After the students learned about the general structures and functions of the respiratory, circulatory, and muscular systems, Miss Scott asked the students to brainstorm what happens to their bodies when they exercise. After the students generated a list of the body's responses, Miss Scott asked a seemingly simple question, "Which organ system is affected the most by exercise?" The students discussed their thoughts and formed three groups, with each group assigned one of the three systems.

Each group designed an experiment to measure the response to running of their group's system of interest. Students identified a measurable variable associated with their group's system: heart rate for the circulatory system; breathing rate for the respiratory system; and muscle fatigue (the number of sit-ups) for the muscular system. All the groups used *five* minutes of running on a treadmill—at a ten-minute-per-mile pace—as the standard for exercise. Before starting, Miss Scott checked each group's hypothesis, procedure, and data chart. Each group collected data from five different individuals, shown below:

Responses to Running

	Breathing Rate (Breaths/Minute)					
	Student 1	Student 2	Student 3	Student 4	Student 5	Average
Before Exercise	15	20	14	17	15	16
After Exercise	26	36	27	29	33	30

	Heart Rate (Beats/Minute)					
	Student 1	Student 2	Student 3	Student 4	Student 5	Average
Before Exercise	74	69	82	65	75	73
After Exercise	140	120	155	135	145	139

	Repetition Rate (Number of Sit-ups/Minute)					
	Student 1	Student 2	Student 3	Student 4	Student 5	Average
Before Exercise	36	30	40	24	27	31
After Exercise	36	24	34	19	22	27

The students were not surprised by their findings. Exercise increased heart and breathing rates and reduced the amount of sit-ups a student could complete. But which system was affected the most? The class discussed this essential question and decided to calculate the percent change for the average response of each system. With the help of Miss Scott, the students determined that the students' average breathing rate increased 88%, heart rate increased 90%, and repetition rate decreased 13%.

Miss Scott helped the students interpret the results. The students concluded that while the heart experienced the greatest change, the whole circulatory system was not necessarily affected the most. The students realized they would need more information about how the circulatory system responded to exercise; perhaps changes in blood pressure would help them gauge how the whole system responded. The students also discussed the similarities between the changes in heart and breathing rate. Miss Scott asked the students why the breathing and heart rate changes were so similar and the repetition rate changed so little. The students described how the respiratory and circulatory system worked together to provide the muscles with oxygen to do work. Because the circulatory and respiratory system responded to the needs of the muscles, the muscles were able to keep working.

WHAT IT LOOKS LIKE IN THE CLASSROOM

Miss Scott then asked, "Why do the muscles need so much oxygen when they are being worked?" The students explained that to move, the muscles require energy, and oxygen probably had something to do with making energy. This led to a short discussion of how cells make energy, including students' reference to prior learning about the role of mitochondria. The students had difficulty with the details, however, so Miss Scott provided them with a short reading passage on cellular respiration. She asked the students to think about how the circulatory and respiratory systems were involved in cellular respiration as they read the passage. After reading the passage, the students individually created a diagram of cellular respiration that detailed the relationships among the circulatory and respiratory systems and the cell. One student asked Miss Scott where the amino acids, glucose, fatty acids, and glycerol came from for cellular respiration. She wrote the student's question on the board and told the class that the question would be the focus of their next investigation.

Assessment Strategies

1. Students should be provided early in the lesson with a rubric that clearly outlines the expectations for the laboratory investigation. Students can use this rubric to self-evaluate their work.
2. Students can develop a labeled diagram detailing the path of oxygen into the body to the cells of a muscle, and the path of carbon dioxide from a cell out of the body.
3. Students can independently create a plan for a bicyclist to maximize her or his performance during a two-day 100-mile race.

Biology Learning Standards

High School

2.5 Explain the important role that ATP serves in metabolism.

4.2 Explain how the circulatory system (heart, arteries, veins, capillaries, red blood cells) transports nutrients and oxygen to cells and removes cell wastes. …(see page 55 for entire standard)

4.3 Explain how the respiratory system (nose, pharynx, larynx, trachea, lungs, alveoli) provides exchange of oxygen and carbon dioxide.

4.5 Explain how the muscular/skeletal system (skeletal, smooth and cardiac muscles, bones, cartilage, ligaments, tendons) works with other systems to support the body and allow for movement. Recognize that bones produce blood cells.

4.8 Recognize that the body's systems interact to maintain homeostasis. Describe the basic function of a physiological feedback loop.

Scientific Inquiry Skills Standards - High School

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

- Pose questions and form hypotheses based on personal observations, scientific articles, experiments, and knowledge.

SIS2. Design and conduct scientific investigations.

- Articulate and explain the major concepts being investigated and the purpose of an investigation.
- Select required materials, equipment, and conditions for conducting an experiment.

SIS3. Analyze and interpret results of scientific investigations.

- Present relationships between and among variables in appropriate forms.
- Use results of an experiment to develop a conclusion to an investigation that addresses the initial questions and supports or refutes the stated hypothesis.

SIS4. Communicate and apply the results of scientific investigations.

- Develop descriptions of and explanations for scientific concepts that were the focus of one or

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more investigations.
Review information, explain statistical analysis, and summarize data collected and analyzed as the result of an investigation.

Chemistry and Physics

The physical sciences (chemistry and physics) examine the physical world around us. Using the methods of the physical sciences, students learn about the composition, structure, properties, and reactions of matter, and the relationships between matter and energy.

Students are best able to build understanding of the physical sciences through hands-on exploration of the physical world. This *Framework* encourages repeated and increasingly sophisticated experiences that help students understand properties of matter, chemical reactions, forces and motion, and energy. The links between these concrete experiences and more abstract knowledge and representations are forged gradually. Over the course of their schooling, students develop more inclusive and generalizable explanations about physical and chemical interactions.

Tools play a key role in the study of the physical world, helping students to detect physical phenomena that are beyond the range of their senses. By using well-designed instruments and computer-based technologies, students can better explore physical phenomena in ways that support greater conceptual understanding.

- In **high school Chemistry**, students learn about the properties of matter and how these properties help to organize elements on the periodic table. 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. Students learn about chemical reactions that occur around us everyday as they learn about chemical reactions such as oxidation-reduction, combustion, and decomposition. 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.

  Learning standards for high school Chemistry fall under the following eight subtopics: *Properties of Matter; Atomic Structure and Nuclear Chemistry; Periodicity; Chemical Bonding; Chemical Reactions and Stoichiometry; States of Matter, Kinetic Molecular Theory, and Thermochemistry; Solutions, Rates of Reaction, and Equilibrium;* and *Acids and Bases and Oxidation-Reduction Reactions.*

- In **high school Introductory Physics**, 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 of introductory physics 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 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.

Learning standards for high school Introductory Physics fall under the following six subtopics: *Motion and Forces; Conservation of Energy and Momentum; Heat and Heat Transfer; Waves; Electromagnetism;* and *Electromagnetic Radiation.*

Physical Science learning standards are also grouped under Broad Topics in Appendix I, which highlights the relationships of standards among grade spans.

Chemistry, High School

Learning Standards for a Full First-Year Course

I. CONTENT STANDARDS

1. Properties of Matter

Central 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 (e.g., density, melting point, boiling point, conductivity, malleability) and chemical properties (e.g., 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

Central Concepts: 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 lead to the formation of elements.

2.1 Recognize discoveries from Dalton (atomic theory), Thomson (the electron), Rutherford (the nucleus), and Bohr (planetary model of atom), and understand how each discovery leads to 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

Central Concepts: Repeating (periodic) patterns of physical and chemical properties occur among elements that define families with similar properties. The periodic table displays the repeating patterns, which are related to the atoms' 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 to the reactivity of other elements in the table.
3.4 Identify trends on the periodic table (ionization energy, electronegativity, and relative sizes of atoms and ions).

4. Chemical Bonding
Central 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 molecular 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 (e.g., surface tension, capillary action, density, 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
Central Concepts: 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 (replacement), double displacement, and combustion.
5.3 Use the mole concept to determine number of particles and molar mass for 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
Central Concepts: Gas particles move independently of each other and are far apart. The behavior of gas particles can be modeled by the kinetic molecular theory. In liquids and solids, unlike gases, 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 273 K and 1 atmosphere (STP).

6. States of Matter, Kinetic Molecular Theory, and Thermochemistry (cont.)

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

Central Concepts: Solids, liquids, and gases dissolve to form solutions. Rates of reaction and chemical equilibrium are dynamic processes that are significant in many systems (e.g., biological, ecological, 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 (e.g., temperature, concentration, surface area, pressure, 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, catalyst).
7.6 Predict the shift in equilibrium when a 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

Central Concepts: 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 constitute 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 donors and acceptors.
8.2 Relate hydrogen ion concentrations to the pH scale and to acidic, basic, and neutral solutions.

Compare and contrast the strengths of various common acids and bases (e.g., vinegar, baking soda, soap, citrus juice).

8.3 Explain how a buffer works.

8.4 Describe oxidation and reduction reactions and give some everyday examples, such as fuel burning and corrosion. Assign oxidation numbers in a reaction.

II. SCIENTIFIC INQUIRY SKILLS STANDARDS

Scientific literacy can be achieved as students inquire about chemical phenomena. The curriculum should include substantial hands-on laboratory and field experiences, as appropriate, for students to develop and use scientific skills in chemistry, along with the inquiry skills listed below.

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

- Observe the world 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.

- 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 appropriate levels of precision
    - collecting data or evidence in an organized way
- Properly use instruments, equipment, and materials (e.g., scales, probeware, meter sticks, microscopes, computers) including set-up, calibration (if required), technique, maintenance, and storage.
- Follow safety guidelines.

SIS3. Analyze and interpret results of scientific investigations.

- Present relationships between and among variables in appropriate forms.
    - Represent data and relationships between and among variables in charts and graphs.
    - Use appropriate technology (e.g., graphing software) and other tools.
- Use mathematical operations to analyze and interpret data results.
- Assess the reliability of data and identify reasons for inconsistent results, such as sources of error or uncontrolled conditions.

- 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.

- Develop descriptions of and explanations for scientific concepts that were a focus of one or more investigations.
- Review information, explain statistical analysis, and summarize data collected and analyzed as the result of 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 (e.g., presentation software) 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,* 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 (e.g., length, volume, mass, temperature, time)
- ✓ Convert within a unit (e.g., centimeters to meters).
- ✓ Use common prefixes such as *milli-, centi-,* and *kilo-*.
- ✓ Use scientific notation, where appropriate.
- ✓ Use ratio and proportion to solve 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 (g); length (cm); and time (s).
- ✓ Use the Celsius and Kelvin scales.

Chemistry, High School

Learning Standards for a Full First-Year Course

Introductory Physics, High School

Learning Standards for a Full First-Year Course

I. CONTENT STANDARDS

1. Motion and Forces
Central Concept: Newton's laws of motion and gravitation describe and predict the motion of most objects.

1.1 Compare and contrast vector quantities (e.g., displacement, velocity, acceleration force, linear momentum) and scalar quantities (e.g., distance, speed, energy, mass, 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
Central 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 Provide and interpret examples showing 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
Central Concept: Heat is energy that is transferred by the processes of convection, conduction, and radiation between objects or regions that are at different temperatures.

3.1 Explain how heat energy is transferred by convection, conduction, and 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 among evaporation, condensation, cooling, and warming.

3. Heat and Heat Transfer (cont.)

3.4 Explain the relationships among temperature changes in a substance, the amount of heat transferred, the amount (mass) of the substance, and the specific heat of the substance.

4. Waves

Central 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, 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

Central 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. Explain that energy can produce a separation of charges.
5.2 Develop qualitative and quantitative understandings of current, voltage, resistance, and the connections among them (Ohm's law).
5.3 Analyze simple arrangements of electrical components in both series and parallel circuits. Recognize symbols and understand the functions of common circuit elements (battery, connecting wire, switch, fuse, 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

Central 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 locations 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.

Introductory Physics, High School

Learning Standards for a Full First-Year Course

II. Scientific Inquiry Skills Standards

Scientific literacy can be achieved as students inquire about the physical world. The curriculum should include substantial hands-on laboratory and field experiences, as appropriate, for students to develop and use scientific skills in introductory physics, along with the inquiry skills listed below.

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

- Observe the world 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.

- 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 appropriate levels of precision
    - collecting data or evidence in an organized way
- Properly use instruments, equipment, and materials (e.g., scales, probeware, meter sticks, microscopes, computers) including set-up, calibration (if required), technique, maintenance, and storage.
- Follow safety guidelines.

SIS3. Analyze and interpret results of scientific investigations.

- Present relationships between and among variables in appropriate forms.
    - Represent data and relationships between and among variables in charts and graphs.
    - Use appropriate technology (e.g., graphing software) and other tools.
- Use mathematical operations to analyze and interpret data results.
- Assess the reliability of data and identify reasons for inconsistent results, such as sources of error or uncontrolled conditions.
- 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.

- Develop descriptions of and explanations for scientific concepts that were a focus of one or more investigations.
- Review information, explain statistical analysis, and summarize data collected and analyzed as the result of 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 (e.g., presentation software) 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,* 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 (e.g., length, volume, mass, temperature, time)
- ✓ Convert within a unit (e.g., centimeters to meters).
- ✓ Use common prefixes such as *milli-, centi-,* and *kilo-*.
- ✓ Use scientific notation, where appropriate.
- ✓ Use ratio and proportion to solve 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/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 the Celsius and Kelvin scales.

WHAT IT LOOKS LIKE IN THE CLASSROOM

Accelerating Cars

Introductory Physics, High School

Acceleration is a concept Ms. Luke chooses to teach students early in her introductory physics class. Many students are aware that acceleration means that an object moves faster, but Ms. Luke has found that students often have difficulty articulating how to measure acceleration and graphically relating acceleration to changes in speed. She decides to teach these concepts by using something with which all her students are familiar; cars.

In an opening dialog, Ms. Luke and her students together define speed and velocity, and how they are calculated. They then move on to the more challenging concept of acceleration, including deceleration, no acceleration, and constant acceleration. Ms. Luke asks, "How can you tell something is accelerating?" One student quickly mentions using a speedometer. Another student mentions "that thing that measures how fast you walk," which Ms. Luke identifies as a pedometer. "How can you use a speedometer, for example, to measure acceleration?" she asks. "Or, if you didn't have an speedometer or pedometer, how would you know that the object is accelerating?"

After listening to student responses, without accepting or dismissing any of them, Ms. Luke proposes that the class go outside to observe whether cars that drive by the front of the school build up speed, slow down, or maintain a constant speed over a given distance. With the data students collect, they will relate what they see and hear to a graph of each car's speed and an analysis of its acceleration.

The students are organized into small groups. Each group stands on the sidewalk along a stretch of road identified by Ms. Luke, separated from the next group by twenty meters. Ms. Luke has already marked off 20-meter increments. She has chosen to use a strip of road that begins at the stop sign in front of the school and includes the downward sloping hill beyond. Here she knows her students will have a good opportunity to observe different rates of speed and acceleration. The students are equipped with stopwatches and their lab notebooks. Each group knows to measure and record the time it takes a car to travel from the stop sign to their position. They are also instructed to record observations of each car while it is in their assigned zone, including the sound of its engine and whether the brake lights are on. The groups record data for five cars identified by Ms. Luke before going back into class to work through their calculations, graph their data, and answer the key questions of the activity.

Upon reentering the classroom, the students record their data on the board. Ms. Luke asks one student to demonstrate how to calculate the speed of one car, within that student's assigned zone, using the data from the student's group plus the data of the group positioned just uphill of them. Each group then records the speed of each car in their zone on a class chart for everyone to see. Ms. Luke also asks students to relate these calculations to their observations of the cars. Ms. Luke then asks her students to consider, "What does the graph of the speed of each car over the entire stretch of road look like?" She has each student make a position vs. time graph and a velocity vs. time graph for each car. Ms. Luke has the students annotate each graph with their observations of that car. From these graphs the class compares change in speed for the cars relative to each other.

Ms. Luke then asks the class to focus on the speed vs. time graph of the first car, which she projects for everyone to see. They notice that the points on the graph do not form a continuous straight line across the grid, but instead go up, straight across, and then down slightly in the last segment. "What does this mean?" she asks. "It means that the car sped up and slowed down," offers one student. "It means that the car accelerated from here to here," another student points out on the graph, "but then it stopped speeding up from here to here." She asks the students to confirm this against their observations of the car.

Ms. Luke then says to the class, "Determine if each car accelerated, decelerated, or showed no acceleration over any period of time. If a car did accelerate or decelerate at some time, did it keep doing so at the same rate?"

Finally, Ms. Luke instructs the students to circle and notate the places on each graph where that car possibly accelerated, decelerated, or showed no acceleration. To quantify the areas circled, she has the students calculate the acceleration from one zone to the next, pointing out that a negative result means that the car slowed down or decelerated, and a zero result means that the car maintained its speed. Ms. Luke also instructs her students to look for instances where the acceleration is the same for two or more adjacent places on the graph, and to label those instances as constant acceleration.

Assessment Strategies

- Students should pay particular attention to the construction and labeling of graphs. They should use units appropriately throughout their work.
- Students can write out a scenario that aligns with the changes in speeds on the graphs they have created themselves. Students should properly use the terms "speed," "velocity," "acceleration," "deceleration," "no acceleration," and "constant acceleration" in their scenarios.
- As a follow-up assignment, the students can create a data chart that includes distance, time, and speed of a fictitious vehicle. With this data, they create a speed vs. time graph. Their data must show acceleration, deceleration, no acceleration, and constant acceleration on their graph. They should also calculate acceleration.

Introductory Physics Learning Standards

High School

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

Scientific Inquiry Skills Standards that apply

High School

SIS2. Design and conduct scientific investigations.

- Employ appropriate methods for accurately and consistently
  - making observations
  - making and recording measurements at appropriate levels of precision
  - collecting data or evidence in an organized way

SIS3. Analyze and interpret results of scientific investigations.

- Use mathematical operations to analyze and interpret data results.

SIS4. Communicate and apply the results of scientific investigations.

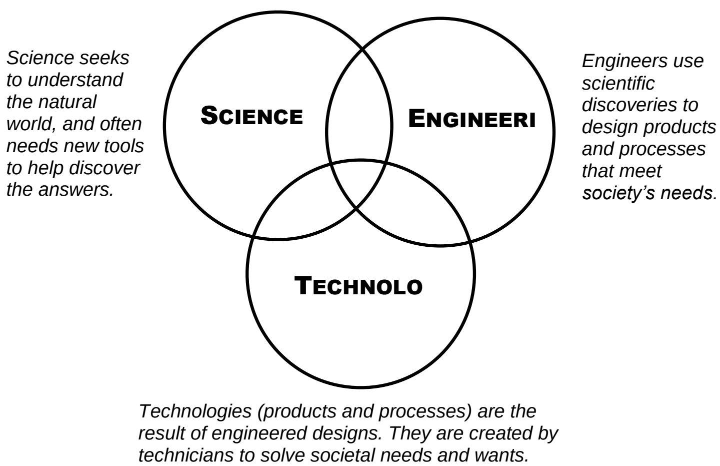
- Explain diagrams and charts that represent relationships of variables.

Technology/Engineering

Technology/engineering works in conjunction with science to expand our capacity to understand the world. Science investigates the natural world. The goal of engineering is to solve practical problems through the development or use of technologies, based on the scientific knowledge gained through investigation.

For example, the planning, design, and construction of the Central Artery Tunnel project in Boston (the “Big Dig”) was a complex and technologically challenging project that drew on knowledge of earth science and physics, as well as on construction and transportation technologies. Scientists and engineers apply scientific knowledge of light to develop lasers, fiber optic technologies, and other technologies in medical imaging. They also apply this scientific knowledge to develop such modern communications technologies as telephones, fax machines, and electronic mail.

The Relationships Among Science, Engineering, and Technology



Although the term *technology* is often used by itself to describe the educational application of computers in a classroom, computers and instructional tools that use computers are only a few of the many technological innovations in use today. The focus of this Technology/Engineering strand is on applied technologies such as engineering design, construction, and transportation, not on instructional technology such as computer applications for classrooms.

Technologies developed through engineering include the systems that provide our houses with water and heat; roads, bridges, tunnels, and the cars that we drive; airplanes and spacecraft; cellular phones, televisions, and computers; many of today’s toys; and systems that create special effects in movies. Each of these came about as the result of recognizing a need or problem and creating a technological solution using the engineering design process, as illustrated in the figure on page 84. Beginning in the early grades and continuing through high school, students carry out this design process in ever more sophisticated ways. As they gain more experience and knowledge, they are able to draw on other disciplines, especially mathematics and science, to understand and solve problems.

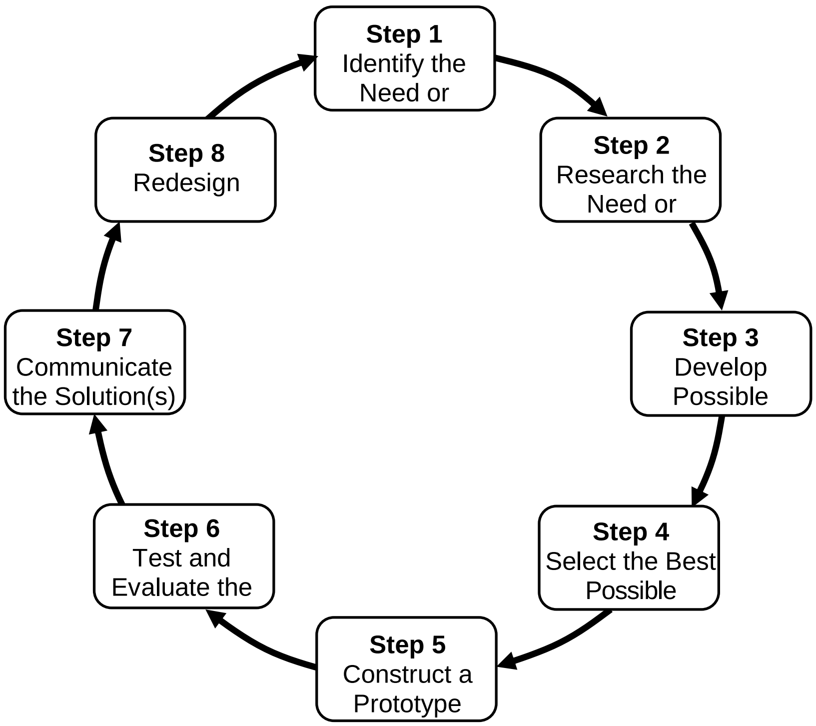
- In **high school,** students develop their ability to solve problems in technology/engineering using mathematical and scientific concepts. High school students are able to relate concepts and principles they have learned in science with knowledge gained in the study of technology/engineering. For example, 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 a high school technology/engineering 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, develop possible solutions, design and build prototypes or models, test the prototypes or models, and make modifications as necessary. Throughout the process of engineering design, high school students are able to work safely with hand and/or power tools, various materials and equipment, and other resources. In high school, courses in technology/engineering should be taught by teachers who are certified in that discipline and who are familiar with the safe use of tools and machines.

  Learning standards for high school fall under the following seven subtopics: *Engineering Design; Construction Technologies; Energy and Power Technologies—Fluid Systems; Energy and Power Technologies—Thermal Systems; Energy and Power Technologies—Electrical Systems; Communication Technologies;* and *Manufacturing Technologies.*

Technology/Engineering learning standards are also grouped under Broad Topics in Appendix I, which highlights the relationships of standards among grade spans..

Steps of the Engineering Design Process



1. Identify the need or problem
2. Research the need or problem
   - Examine the current state of the issue and current solutions
   - Explore other options via the Internet, library, interviews, etc.
3. Develop possible solution(s)
   - Brainstorm possible solution(s)
   - Draw on mathematics and science
   - Articulate the possible solution(s) in two and three dimensions
   - Refine the possible solution(s)
4. Select the best possible solution(s)
   - Determine which solution(s) best meet(s) the original need or solve(s) the original problem
5. Construct a prototype
   - 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 initial need or the problem
   - Discuss societal impact and tradeoffs of the solution(s)
8. Redesign
   - Overhaul the solution(s) based on information gathered during the tests and presentation

Technology/Engineering, High School

Learning Standards for a Full First-Year Course

I. Content Standards

(Suggested learning activities related to the high school Technology/Engineering learning standards are listed on pages 98–99.)

1. Engineering Design

Central Concepts: 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: 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 examples of technologies, objects, and processes that have been modified to advance society, and explain why and how they were modified.

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

1.4 Interpret and apply scale and proportion to orthographic projections and pictorial drawings (e.g., 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

Central Concepts: The construction process is a series of actions taken 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 technology.

2.1 Identify and explain the engineering properties of materials used in structures (e.g., elasticity, plasticity, R value, density, 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, power tools, and measurement devices used in construction.

2.6 Recognize the purposes of zoning laws and building codes in the design and use of structures.

3. Energy and Power Technologies—Fluid Systems

Central Concepts: Fluid systems are made up of liquids or gases and allow force to be transferred from one location to another. They can also provide water, gas, and/or oil, and/or 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 a fluid system.

3.1 Explain the basic differences between open fluid systems (e.g., irrigation, forced hot air system, air compressors) and closed fluid systems (e.g., forced hot water system, hydraulic brakes).

3. Energy and Power Technologies—Fluid Systems (cont.)

3.2 Explain the differences and similarities between hydraulic and pneumatic systems, and explain 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 moving in a pipe varies inversely with changes in the cross-sectional area of the pipe.

3.5 Identify and explain sources of resistance (e.g., 45º elbow, 90º elbow, changes in diameter) for water moving through a pipe.

4. Energy and Power Technologies—Thermal Systems

Central Concepts: 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 a thermal system.

4.1 Differentiate among conduction, convection, and radiation in a thermal system (e.g., heating and cooling a house, 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 (e.g., wind and solar energy conversion systems).

5. Energy and Power Technologies—Electrical Systems

Central Concepts: 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 an electrical system.

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 relationships among voltage, current, and resistance in a simple circuit, using Ohm's law.

5.4 Recognize that resistance is affected by external factors (e.g., temperature).

5.5 Compare and contrast alternating current (AC) and direct current (DC), and give examples of each.

6. Communication Technologies
Central Concepts: Applying technical processes to exchange information can include 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 a communication technology.

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 (e.g., computers, cell phones).
6.3 Explain how the various components (source, encoder, transmitter, receiver, decoder, destination, storage, and retrieval) and processes of a communication system function.
6.4 Identify and explain the applications of laser and fiber optic technologies (e.g., telephone systems, cable television, photography).
6.5 Explain the application of electromagnetic signals in fiber optic technologies, including critical angle and total internal reflection.

7. Manufacturing Technologies
Central Concepts: Manufacturing processes can be classified into six groups: casting/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 a manufacturing technology.

7.1 Describe the manufacturing processes of casting and molding, forming, separating, conditioning, assembling, and finishing.
7.2 Identify the criteria necessary to select safe tools and procedures for a manufacturing process (e.g., properties of materials, required tolerances, end-uses).
7.3 Describe the advantages of using robotics in the automation of manufacturing processes (e.g., increased production, improved quality, 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 other resources necessary to engage in these tasks. Students may also engage in design challenges that provide constraints and specifications to consider as they develop a solution to a problem.

Steps of the Engineering Design Process*
1. Identify the need or problem
2. Research the need or problem
    - Examine current state of the issue and current solution(s)
    - Explore other options via the Internet, library, interviews, etc.
3. Develop possible solution(s)
    - Brainstorm possible solution(s)
    - Draw on mathematics and science
    - Articulate the possible solution(s) in two and three dimensions
    - Refine the possible solution(s)

Steps of the Engineering Design Process (cont.)

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 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 also listed under the first content standard of the Engineering Design subtopic in this course.*

III. Mathematical Skills

Students are expected to know the content of the *Massachusetts Mathematics Curriculum Framework,* 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 (e.g., length, volume, mass, temperature, time)
- ✓ Use both metric/standard international (SI) and U.S. Customary (English) systems of measurement.
- ✓ Convert within a unit (e.g., centimeters to meters, inches to feet).
- ✓ Use common prefixes such as *milli-, centi-,* and *kilo-*.
- ✓ Use scientific notation, where appropriate.
- ✓ Use ratio and proportion to solve 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); power (W); electric current (A); electric potential difference/voltage (V); and electric resistance (Ω).
- ✓ Use the Celsius and Fahrenheit scales.

What It Looks Like in the Classroom

A Look at Energy-Efficient Homes

Adapted from *Standards for Technological Literacy*, p. 197

Technology/Engineering, High School

The city of Westlake and the surrounding areas experienced an accelerated growth in the construction industry, especially in new home construction. The local high school technology teacher, Mr. Morales, thought it would be helpful for his students, as future consumers, to have an in-depth understanding of the housing industry and to know about the latest developments in home construction techniques, materials, and practices.

Mr. Morales decided to organize a lesson where students were invited to participate in designing an energy-efficient home for a family of four. He guided the students to consider all forms of energy and not to limit their imaginations. Students were instructed to consider costs of using energy-efficient designs and how those costs might affect the resale value of a home.

He instructed the students in his technology class to individually design, draw, and build a scale model of a residential home using heating and cooling systems that were energy-efficient, aesthetically pleasing, functional, marketable, and innovative. The house also had to accommodate a family of four with a maximum size of 2100 square feet. Each student had to work within a budget of $150,000, and had nine weeks to complete the project.

The students began by researching homes in their city that already incorporated features that were required in their project. They conducted library and Internet searches to learn about the latest materials and techniques available in the housing industry. Students also interviewed local architects and building contractors to learn about current practices and how these professionals were integrating innovative features. For example, the students learned about incorporating increased day lighting, which takes into account the home's orientation, into the design of the home. They also learned about designing and installing environmentally sound, energy-efficient systems and incorporating whole-home systems that are designed to provide house maintenance, home security, and indoor air-quality management.

The students then began the process of sketching their homes. Many students had to gather additional research as they realized they needed more information to complete their sketches. Using their sketches, the students built scale models of their homes out of mat board.

A group of building industry professionals from across the area was invited to evaluate students' work and provide feedback on their ideas in several categories, including design, planning, innovation, energy conservation features, drawing presentation, model presentation, and exterior design.

As a result of this experience, the students learned firsthand what it takes to design a home for the 21st century. Students also learned how to successfully plan and select the best possible solution from a variety of design ideas in order to meet criteria and constraints, as well as how to communicate their results using graphic means and three-dimensional models.

What It Looks Like in the Classroom

Assessment Strategies

- Students can research building codes and zoning laws in the community, then each can write a detailed informational report.
- Students can compare construction efficiency for various house designs, evaluating the advantages and disadvantages of each design (e.g., ranch vs. colonial, lumber vs. steel framework). They can then create a chart illustrating the differences.
- Students can create an engineering presentation illustrating the design and efficiency of the prototype, using appropriate visual aids (e.g., charts, graphs, presentation software). The presentation should include any other factors that impact the design of the house (e.g., site, soil conditions, climate).
- Students will use a rubric to assess design specification, heat efficiency, and final prototype of the design challenge.

Engineering Design Learning Standards

High School

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

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

1.4 Interpret and apply scale and proportion to orthographic projections and pictorial drawings (e.g., ¼" = 1'0", 1 cm = 1 m).

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

Construction Technologies Learning Standards

High School

2.1 Identify and explain the engineering properties of materials used in structures (e.g., elasticity, plasticity, R value, density, strength).

2.6 Recognize the purposes of zoning laws and building codes in the design and use of structures.

Energy and Power Technologies—Thermal Systems Learning Standards

High School

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.

Suggested Learning Activities for High School Technology/Engineering Learning Standards

Please note: The number(s) in parentheses following each suggested learning activity refer to the related high school Technology/Engineering learning standard(s).

1. Engineering Design

- Create an engineering design presentation using multimedia, oral, and written communication. (1.1)
- Choose the optimal solution to a problem, clearly documenting ideas against design criteria and constraints, and explain how human values, economics, ergonomics, and environmental considerations have influenced the solution. (1.1)
- Visit a local industry in any area of technology and describe the research and development processes of the company. (1.1, 1.5)
- Have students utilize library/Internet resources to research the patent process. (1.1, 1.2, 1.5)
- Create pictorial and multi-view drawings that include scaling and dimensioning. (1.2, 1.3, 1.4, 1.5)
- Create plans, diagrams, and working drawings in the construction of a prototype. (1.2, 1.3, 1.4, 1.5)

2. Construction Technologies

- Demonstrate the transmission of loads for buildings and other structures. (2.1, 2.2, 2.6)
- Construct a truss and analyze to determine whether the members are in tension, compression, shear, and/or torsion. (2.1, 2.3, 2.4, 2.5)
- Given several types of measuring tools and testing tools, give students a challenge and have them evaluate the effectiveness of a tool for the given challenge. (2.2)
- Construct and test geometric shapes to determine their structural advantages depending on how they are loaded. (2.3, 2.5, 2.6)
- Using a chart from the state building code, students should be able to correctly use the stress-strain relationship to calculate the floor joist size needed. (2.4, 2.6)
- Design and conduct a test for building materials (e.g., density, strength, thermal conductivity, specific heat, moisture resistance). (2.4, 2.5)
- Calculate the live load for the second floor of a building and show how that load is distributed to the floor below. (2.5, 2.6)
- Identify ways to protect a watershed (e.g., silt barriers, hay bales, maintenance of watershed areas). (2.5)

3. Energy and Power Technologies—Fluid Systems

- Demonstrate how appropriate selection of piping materials, pumps, and other materials is based on hydrostatic effects. (3.1, 3.5)
- Demonstrate how a hydraulic brake system operates in an automobile. (3.1, 3.5)
- Design a private septic system while considering the type of soil in the leach field. (3.1, 3.4)
- Identify similar and differing elements of a public sewer system and a private septic system. (3.1, 3.4)
- Explain engineering control volume concepts as applied to a domestic water system.

Suggested Learning Activities for High School Technology/Engineering Learning Standards

Does the amount of water entering a residence equal the amount of water leaving the residence? (3.5)

- Design an airfoil or spoiler to demonstrate Bernoulli's principle. (3.3)
- Create a hydraulic arm powered by pistons that is capable of moving in three dimensions. (3.4)

3. Energy and Power Technologies—Fluid Systems (cont.)

- Have students do a simple calculation with velocity and cross-sectional pipe size. Velocity times cross-sectional area is a constant. As the pipe size changes, the velocity will have to change as well. For example, if the pipe changes from a 2-inch diameter to a 1-inch diameter, the velocity will quadruple. (3.5)

4. Energy and Power Technologies—Thermal Systems

- Create a model (e.g., the multi-layer wall of a building) to test the concept of conduction, and compute heat losses. (4.1, 4.2, 4.4)
- Design and build a hot water solar energy system consisting of a collector, hoses, pump (optional), and storage tank. After the system has been heated, calculate the heat gains achieved through solar heating. (4.1)
- Design and build a model to test heat losses through various materials and plot the results. (4.2, 4.5)
- Design and build a solar cooker for various food substances. Each student should design a solar cooker for her or his specific food. (4.1, 4.2)
- Design an awning for a business based upon seasonal changes and the angles of the sun. (4.2)

5. Energy and Power Technologies—Electrical Systems

- Design and create an electrical system containing a source, a switch, and multiple loads. Be able to measure the voltage and current at each load. (5.2)
- Design and create an electrical system with either motors, all operating at different speeds, or lamps, all operating at different intensities. (5.2, 5.3)
- Create schematics for series, parallel, and combination (series-parallel) circuits, and construct each type of circuit from its schematic. (5.4)

6. Communication Technologies

- Give an example of each of the following types of communication: human to human (talking), human to machine (telephone), machine to human (facsimile machine), and machine to machine (computer network). (6.4)
- Create prototypes for the following specific types of communication: human to human (e.g., talking, telephone), human to machine (e.g., keyboard, cameras), machine to human (e.g., CRT screen, television, printed material), machine to machine (e.g., CNC, internetworking). (6.2, 6.3, 6.4)
- Define size and focal length for a lens and explain their applications in light theory. (6.5)
- Research a communication technology and the impact that lasers or fiber optics have had on that technology. (6.4, 6.5)

Suggested Learning Activities for High School Technology/Engineering Learning Standards

7. Manufacturing Technologies

- Design a system for mass producing a product. (7.1, 7.2)
- Design, build, and program a robotic device capable of moving through three axes. (7.3)

Appendix I

PreK through High School Learning Standards Organized by Strand and Broad Topics

Planning science and technology/engineering curriculum at any grade level is most effective when it is known what students have already been taught and what they should be learning in subsequent years. It can be helpful in planning and aligning curricula to recognize how standards across grade spans may be integrated, as is often done in elementary and middle school grades.

Please note the Physical Sciences strand has been split in this appendix into Chemistry and Introductory Physics to effectively show concepts across the grade spans. Even so, there is some redundancy in the grade PreK through grade 8 standards in these two outlines.

This appendix shows which standard(s) in each grade span fall under each of these Broad Topics. Schools or districts may choose, however, to group standards in combinations other than those shown in this appendix. Organizing the standards by strand and Broad Topic provides an opportunity to see how students are supported in learning any one concept from year to year.

Learning standards are not quoted verbatim in this appendix; rather, the basic content and intent of the standard is listed, along with its number. Please refer to the actual standards in the third chapter of the document for the full articulation of each standard, including the complete scope of each topic or concept.

Broad Topic	Content of Each Learning Standard			
	PreK–2	Grades 3–5	Grades 6–8	High School
Energy in the Earth System	3. Weather changes from day to day and over the seasons. 4. The sun supplies heat and light to the earth and is necessary for life.	6. Air temperature, moisture, wind speed and direction, and precipitation make up the weather in a particular place and time. 7. Various forms of precipitation are connected to the weather in a particular place and time. 8. Global patterns influence local weather, which can be measured. 9. Weather is different from climate.	3. Radiation, conduction, and convection transfer heat through the earth's system. 4. Energy provided by the sun, global patterns of atmospheric movement, and temperature differences among water, land, and atmosphere are related. 11. Earth's tilt and its revolution around the sun result in uneven heating, causing the seasons.	1.1 Earth's principal sources of internal and external energy. 1.2 Characteristics of electromagnetic radiation and its impact on life and Earth's systems. 1.3 The transfer of energy through radiation, conduction, and convection contributes to global atmospheric processes. 1.4 Unequal heating of Earth and the Coriolis effect influence global circulation patterns and impact Massachusetts weather and climate. 1.5 The revolution of Earth around the Sun and the inclination of Earth on its axis cause Earth's seasonal variations. 1.6 Conditions associated with frontal boundaries and cyclonic storms and their impact on human affairs. 1.7 Oceanic currents relate to global circulation within the marine environment and climate. 1.8 Ground-based observations, satellite data, and computer models are used to demonstrate interconnected Earth systems.
Materials and Energy Resources	1. Water, rocks, soil, and living organisms are found on the earth's surface. 2. Air is a mixture of gases all around us and wind is moving air.	1. What a mineral is. 2. Physical properties of minerals and tests for those. 5. The properties of soil include color, texture, and the abilities to retain water and support the growth of plants.		2.1 Renewable energy resources and nonrenewable energy resources. 2.2 Effects on the environment and on the carbon cycle of using renewable and nonrenewable resources.
Earth Processes and Cycles		3. The three categories of rocks and the processes that create them. 4. Soil is formed by the weathering of rock and decomposition of plant and animal remains. 10. Water on earth cycles in different forms and locations. 11. Cycling of water, both in and out of the atmosphere, has an effect on climate.	6. Earth's surface is built up and torn down by natural processes.	3.1 Physical and chemical weathering leads to erosion and formation of soils and sediments, and creates the various types of landscapes. 3.2 The carbon cycle. 3.3 The nitrogen cycle. 3.4 Water flows into and through a watershed. 3.5 The hydrologic cycle includes evaporation, condensation, precipitation, surface runoff and groundwater percolation, infiltration, and transpiration. 3.6 The rock cycle, including the formation and physical properties of igneous, sedimentary, and metamorphic rocks.

Structure of the Earth		12. Earth's surface changes due to slow processes such as erosion and weathering, and rapid processes such as landslides, volcanic eruptions, and earthquakes.	1. Earth's common physical features can be represented with models and maps. 2. Layers of the earth include the lithosphere, mantle, and core. 5. Movement of the earth's crustal plates causes both slow and rapid changes in the earth's surface. 7. Physical evidence supports theories that the earth has evolved over geologic time.	3.7 Absolute and relative dating methods are used to measure geologic time. 3.8 The development of a lithospheric plate from its growth to its destruction, including the recording of magnetic polarity. 3.9 The motion of the lithospheric plates is related to convection currents in Earth's mantle. 3.10 Earthquakes, volcanoes, tsunamis, mountain building, and tectonic uplift are related to plate movements. 3.11 Seismic data are used reveal Earth's interior structure and earthquake epicenters. 3.12 The Richter scale and the relative damage incurred by earthquakes.
Earth in the Solar System	5. Events around us have repeating patterns, including the seasons of the year, day, and night.	13. Earth is a part of the "solar system" that includes the sun, planets, and many moons. Earth is the third planet from the sun. 14. Earth orbits the sun in a year's time and rotates on its axis in approximately 24 hours. The rotation of the earth, day/night, and apparent movements of the sun, moon, and stars are connected. 15. Changes occur in the observable shape of the moon over a month.	8. Gravity is a force that pulls all things toward the center of the earth. Gravity influences the formation and movement of the planets, stars, and solar system. 9. Lunar and solar eclipses, moon phases, and tides are related to relative positions of the earth, moon, and sun. 10. Properties and conditions of objects in the solar system and those on Earth.	4.2 Influence of gravity and inertia on the rotation and revolution of orbiting bodies; Sun-Earth-moon relationships.
Origin and Evolution of Earth			12. The universe contains many billions of galaxies and each galaxy contains many billions of stars.	4.1 The Big Bang Theory and the evidence that supports it. 4.3 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.

Broad Topic PK-8	Broad Topic HS	PreK–2	Grades 3–5	Grades 6–8	High School
Characteristics of Living Things	Characteristics of Living Things	1. Animals and plants are living things that grow, reproduce, & need food, air, & water. 2. Characteristics of living and nonliving things. 3. Plants and animals have life cycles that vary.	1. Physical characteristics of plants and animals 3. Plants and animals go through predictable life cycles, including birth, growth, development, reproduction, and death. 4. Major life cycle stages of the frog and butterfly.	1. Organisms are classified into kingdoms.	2.3 Cellular evidence and modes of nutrition of the six kingdoms.
Structure and Function of Cells	Cell Biology and Biochemistry			2. Organisms are composed of cells, and many organisms are single-celled, where one cell must carry out all basic functions of life. 3. Plant and animal cells have similarities and differences in their major organelles. 4. Basic functions of living organisms are carried out in cells.	1.1 Biological organisms are composed primarily of few elements. 1.2 Molecular structures and functions of the four major categories of organic molecules. 1.3 Enzymes are catalysts for biochemical reactions affected by a variety of factors. 2.1 Cell parts/organelles and their functions; cell membranes. 2.2 Cellular similarities and differences of prokaryotes and eukaryotes. 2.4 Reactants, products, and purposes of photosynthesis and respiration. 2.5 Role of ATP in metabolism. 2.6 The cell cycle and mitosis in asexual reproduction. 2.7 Meiosis in sexual reproduction. 2.8 Differences of a virus and a cell.
Systems in Living Things	Anatomy and Physiology		2. Structures in plants that are responsible for food production, support, water transport, reproduction, growth, and protection.	5. Multicellular organisms can be hierarchically organized from cells to tissues to organs to systems to organisms. 6. General functions of the major systems of the human body, and the interactions of these systems.	4.1 The digestive system converts macromolecules into smaller molecules. 4.2 The circulatory system transports nutrients and oxygen, and removes cell wastes. Kidneys and liver remove waste from blood. 4.3 The respiratory system provides exchange of O_2 and CO_2. 4.4 The nervous system mediates communication. 4.5 The muscular/skeletal system supports the body and allows for movement. Bones produce blood cells. 4.6 Sexual reproductive system. 4.7 Communication among cells is required for coordination of body functions. 4.8 Body systems interact to maintain homeostasis using physiological feedback loops.

Heredity	**Genetics**	4. Plants and animals closely resemble their parents in observed appearance.	5. Observed characteristics of plants and animals can be fully inherited or they can be affected by the climate or environment.	7. Every organism requires a set of instructions that specifies its traits. Heredity is the passage of these instructions from one generation to another. 8. Hereditary information is contained in genes located in the chromosomes of each cell. 9. Sexual reproduction and asexual reproduction.	3.1 DNA structure and its function in genetic inheritance. 3.2 DNA replication transmits and conserves the genetic code. Transcription and translation result in expression of genes. 3.3 Mutations in the DNA sequence or gametes may result in phenotypic changes in an organism or offspring. 3.4 Genetic traits result in observed inheritance patterns. 3.5 Patterns of inheritance can be explained through Mendel's laws of segregation and independent assortment. 3.6 Probabilities for genotype and phenotype combinations in monohybrid crosses can be modeled using a Punnett Square.
Evolution and Biodiversity	**Evolution**	5. Fossils provide us with information about living things that inhabited the earth years ago.	6. Inherited characteristics may change over time as adaptations to changes in the environment enable organisms to survive. 7. Changes in the environment have caused some plants and animals to die or move to new locations.	10. Genetic variation and environmental factors are causes of evolution and the diversity of organisms. 11. Evidence drawn from multiple sources provides the basis of the theory of evolution. 12. Extinction of species is related to a mismatch of adaptation and environment. 17. Ecosystems have changed through geologic time in response to various influences. 18. Biological evolution accounts for species diversity developed over generations.	5.1 Evolution is demonstrated by evidence from multiple sources. 5.2 Species are reproductively distinct groups of organisms. Species are classified into a hierarchical taxonomic system based on similarities. Geographic isolation can play a role in speciation. 5.3 Evolution through natural selection can result in changes in biodiversity through an increase or decrease of genetic diversity within a population.
Living Things and Their Environments	**Ecology**	6. People and other animals interact with the environment through their senses. 7. Animals and plants go through changes in appearance as the seasons change. 8. An organism's habitat provides for its basic needs.	8. Organisms meet needs by using behaviors in response to information from the environment. Some behaviors are instinctive and others learned. 9. Plants have characteristic behaviors. Plants and animals can survive harsh environments via seasonal behaviors. 10. Organisms can cause changes in their environment to ensure survival, which may affect the ecosystem. 11. Energy derived from the sun is used by plants to produce sugars and is transferred within a food chain from producers to consumers to decomposers.	13. Organisms interact and have different functions within an ecosystem that enable the ecosystem to survive. 14. Roles & relationships among producers, consumers, and decomposers in the process of energy transfer in a food web. 15. Dead plants and animals are broken down by other living organisms, which contributes to the system as a whole. 16. Producers use energy from sunlight to make sugars through photosynthesis, which can be used immediately, stored for later use, or used by other organisms.	6.1 Birth, death, immigration, and emigration influence population size. 6.2 Changes in population size and biodiversity result from a variety of influences. 6.3 A food web identifies producers, consumers, and decomposers, and explains the transfer of energy through trophic levels. Relationships among organisms add to the complexity of biological communities. 6.4 Water, carbon, and nitrogen cycle between abiotic resources and organic matter, and oxygen cycles through photosynthesis and respiration.

STRAND: PHYSICAL SCIENCES (CHEMISTRY)

Broad Topic	Content of Each Learning Standard			
	PreK–2	**Grades 3–5**	**Grades 6–8**	**High School**
Properties of Materials and Matter	1. Observable properties of objects include size, shape, color, weight, and texture.	1. Properties of objects and materials.	2. Volume and mass are distinct components of density. 3. Appropriate tools and use of significant digits are needed to measure volume and mass. 4. Mass is conserved in a closed system.	
States of Matter, Kinetic Molecular Theory, and Thermochemistry	2. Objects and materials are solid, liquid, or gas. Solids have a definite shape; liquids and gases take the shape of their container.	2. Solids, liquids, and gases have distinct properties. 3. Water can be changed from one state to another by adding or taking away heat.	9. A substance has a melting point and a boiling point, both independent of the amount of the sample. 10. Physical changes and chemical changes. 15. The effect of heat on particle motion during a change in phase.	1.1 Physical and chemical properties and changes. 1.3 The three normal states of matter in terms of energy, particle motion, and phase transitions. 6.1 Kinetic molecular theory explains the behavior of gases and the relationships among pressure, volume, temperature, and the number of particles in a gas sample. The combined gas law determines changes in pressure, volume, and temperature. 6.2 The ideal gas law and molar volume at 273K and 1 atmosphere. 6.3. Properties of gases, liquids, and solids using kinetic molecular theory; molecular behavior of matter during phase transitions.
Forms of Energy		4. Basic forms of energy, which cause motion or create change. 5. Energy can be transferred from one form to another.	13. Kinetic energy is transformed into potential energy & vice versa. 14. Temperature change results from adding or taking away heat energy from a system. 16. Heat moves in predictable ways, from warmer to cooler objects until reaching equilibrium.	6.4 The law of conservation of energy; endothermic and extothermic processes. 6.5 There is a natural tendency for systems to move in a direction of disorder or randomness (entropy).
Elements, Compounds and Mixtures; Atomic Structure and Nuclear Chemistry			5. Many elements combine in a multitude of ways to produce compounds that make up living and nonliving things. 6. Differences between an atom and a molecule. 7. Basic examples of elements and compounds. 8. Differences between mixtures and pure substances.	1.2 Pure substances and mixtures; heterogeneous and homogeneous mixtures. 2.1 Discoveries of atomic theory, the electron, the nucleus, and the planetary model of atom led to modern theory. 2.2 Rutherford's "gold foil" experiment led to discovering the nuclear atom. Components of the nuclear atom and how they interact. 2.3 The laws of conservation of mass, constant composition, and multiple proportions. 2.4 Electron configurations for twenty elements. 2.5 The three main types of radioactive decay and their properties. 2.6 Process of radioactive decay using nuclear equations and the concept of half-life for an isotope. 2.7 Nuclear fission and nuclear fusion.

Periodicity				3.1 An element's position on the periodic table relates to its atomic number, family, and period. 3.2 Metals, nonmetals, and metalloids on the periodic table. 3.3 An element's position on the periodic table relates to its electron configuration and reactivity. 3.4 Trends on the periodic table.
Chemical Bonding				4.1 Atoms combine through ionic and covalent bonding. Valence electrons can predict chemical formulas. 4.2 Lewis dot structures for simple molecules and ionic compounds. 4.3 Electronegativtiy explains polar and nonpolar covalent bonds. 4.4 Valence-shell electron-pair repulsion theory predicts molecular geometry of simple molecules. 4.5 Hydrogen bonding in water affects a variety of physical, chemical, and biological phenomena. 4.6 Chemical formulas for simple ionic and molecular compounds.
Reactions and Stoichiometry				5.1 Conservation laws are used to balance chemical equations. 5.2 Classifications of chemical reactions. 5.3 The number of particles and molar mass can be determined using the mole concept. 5.4 Percent compositions; empirical and molecular formulas. 5.5 Mass-to-mass stoichiometry for a chemical reaction. 5.6 Percent yield in a chemical reaction
Solutions, Rates of Reaction, and Equilibrium				7.1 Process by which solutes dissolve in solvents. 7.2 Concentration, solution dilution, and solution stoichiometry, using molarity. 7.3 Factors that affect the rate of dissolving. 7.4 The properties of solutions and pure solvents. 7.5 Factors affecting the rate of a chemical reaction. 7.6 The factors and processes that can cause a shift in equilibrium of a system.
Acids and Bases and Oxidation-Reduction Reactions				8.1 Theories of acids and bases in terms of the presence of hydronium and hydroxide ions in water, and proton donors and acceptors. 8.2 The pH scale and acidic, basic, and neutral solutions are related to hydrogen ion concentrations. 8.3 How a buffer works. 8.4 Oxidation and reduction reactions and everyday examples; oxidation numbers in a reaction.

STRAND: PHYSICAL SCIENCES (INTRODUCTORY PHYSICS)

Broad Topic		Content of Each Learning Standard			
PK-8	HS	PreK–2	Grades 3–5	Grades 6–8	High School
Position and Motion of Objects	Motion and Forces	3. Objects can move in various ways. 4. Change the motion of an object by applying a force. The greater the force, the greater the change in motion. 5. Objects can be balanced under some conditions.		1. Weight is the amount of gravitational pull on an object and is distinct from mass. 11. An object's motion can be described by its position, direction of motion, and speed. 12. Distance vs. time graphs for constant speed.	1.1 Vector and scalar quantities. 1.2 Displacement, distance, velocity, speed, and acceleration. 1.3 Graphs of 1-dimensional motion. 1.4 Newton's three laws of motion. 1.5 Free-body force diagrams show forces acting on a system consisting of a pair of interacting objects. 1.6 Qualitative differences between static and kinetic friction, and their effects on the motion of objects. 1.7 Newton's law of universal gravitation. 1.8 Forces involved in circular motion.
Forms of Energy	Conservation of Energy and Momentum		4. Basic forms of energy, which cause motion or create change. 5. Energy can be transferred from one form to another.	13. Kinetic energy can be transformed into potential energy and vice versa.	2.1 The law of conservation of energy. 2.2 Energy can be converted from gravitational potential energy to kinetic energy and vice versa. 2.3 Work can be expressed as a change in mechanical energy. 2.4 Power can be expressed as work done per unit time. 2.5 Linear momentum is the product of mass and velocity and is always conserved.
States of Matter		2. Objects and materials are solid, liquid, or gas. Solids have a definite shape; liquids and gases take the shape of their container.	2. Solids, liquids, and gases have distinct properties. 3. Water can be changed from one state to another by adding or taking away heat.	9. A substance has a melting point and a boiling point, both independent of the amount of the sample.	3.3 Average molecular kinetic energy is related to temperature. Energy is absorbed when a substance changes from a solid to a liquid to a gas, and energy is released when a substance changes from a gas to a liquid to a solid. Relationships exist among evaporation, condensation, cooling, and warming. 3.4 Temperature change in a substance is related to the amount of heat transferred, and the amount and specific heat of the substance.

Heat Energy	**Heat and Heat Transfer**			14. Temperature change results from adding or taking away heat energy from a system. 15. The effect of heat on particle motion during a change in phase. 16. Heat moves in predictable ways, moving from warmer to cooler objects until reaching equilibrium.	3.1 Heat energy is transferred by convection, conduction, and/or radiation. 3.2 Heat energy will move from a higher temperature to a lower temperature until equilibrium is reached.
Electrical and Magnetic Energy	**Electromagnetism**		6. Electricity in circuits requires a complete loop for an electrical current. Electricity can produce light, heat, and sound. 7. Objects and materials can be conductors or insulators of electricity. 8. Making and using electromagnets. 9. Magnets have poles that repel and attract each other. 10. A magnet will attract some objects and materials but not others.		5.1 An electric charge tends to be static on insulators and can move on and in conductors. Energy can produce a separation of charges. 5.2 Current, voltage, resistance, and the connections among them (Ohm’s law). 5.3 Arrangements of components in series and parallel circuits. Symbols are used to represent the functions of common circuit elements in a schematic diagram. 5.4 Attractive or repulsive forces between objects relative to their charges and the distance between them (Coulomb’s law). 5.5 Electric current is a flow of charge caused by a potential difference, and power is equal to current multiplied by voltage. 5.6 Moving electric charges produce magnetic forces and moving magnets produce electric forces. The interplay of electric and magnetic forces is the basis for many technologies.
Sound and Light Energy	**Waves and Radiation**		11. Sound is produced by vibrating objects and travels through a medium. The rate of vibration is related to the pitch of the sound. 12. Light travels in a straight line until it strikes an object or travels from one medium to another. Light can be reflected, refracted, and absorbed.		4.1 The measurable properties of waves and the relationships among them; simple harmonic motion. 4.2 Mechanical and electromagnetic waves. 4.3 Transverse and longitudinal mechanical waves. 4.4 Reflection and refraction of waves. 4.5 Mechanical waves generally move faster through a solid than a liquid and faster through a liquid than a gas. 4.6 The apparent change in frequency of waves due to the motion of a source or a receiver (the Doppler effect). 6.1 Electromagnetic waves are transverse waves and travel at the speed of light through a vacuum. 6.2 Electromagnetic spectrum in terms of frequency and wavelength, and the locations of different waves on the spectrum.

STRAND: TECHNOLOGY/ENGINEERING

Broad Topic	Content of Each Learning Standard			
	PreK–2	**Grades 3–5**	**Grades 6–8**	**High School**
Materials, Tools, and Machines	1.1 Characteristics of natural and human-made materials. 1.2 Possible uses for natural and human-made materials. 1.3 Safe and proper use of tools and materials to construct simple structures.	1.1 Materials used to accomplish a design task based on specific properties. 1.2 Appropriate materials and tools to construct a prototype safely. 1.3 Differences between simple and complex machines.	1.1 Appropriate materials for design tasks based on specific properties and characteristics. 1.2 Appropriate tools used to hold, lift, carry, fasten, and separate, and their safe and proper uses. 1.3 Safe and proper use of tools and machines needed to construct a prototype.	2.5 Safe and proper use of common hand tools, power tools, and measurement devices used in construction.
Engineering Design	2.1 Tools and simple machines used for a specific purpose. 2.2 Human beings and animals use parts of the body as tools.	2.1 Problems that reflect the need for shelter, storage, or convenience. 2.2 Different ways a problem can be represented. 2.3 Relevant design features for building a prototype of a solution to a problem. 2.4 Natural and mechanical systems are designed to serve similar purposes.	2.1 Steps of the engineering design process. 2.2 Methods of representing solutions to a design problem. 2.3 The purpose of a prototype. 2.4 Appropriate materials, tools, and machines to construct a prototype. 2.5 Design features and cost limitations affect the construction of a prototype. 2.6 The five elements of a universal systems model.	1.1 Steps of the engineering design process. 1.2 The engineering design process is used to solve problems, advance society, and modify technologies, objects, and processes. 1.3 Multi-view drawings and pictorial drawings are produced using various techniques. 1.4 Scale and proportion are applied to orthographic projections and pictorial drawings. 1.5 Plans, diagrams, and working drawings are used in the construction of prototypes and models.
Communication			3.1 Components of a communication system. 3.2 Appropriate tools, machines, and electronic devices used to produce and/or reproduce design solutions. 3.3 Communication technologies and systems. 3.4 How symbols and icons are used to communicate a message.	6.1 Information travels through various media. 6.2 Differences between digital and analog signals; how communication devices employ digital and analog technologies. 6.3 How the various components and processes of a communication system function. 6.4 Applications of laser and fiber optic technologies. 6.5 Application of electromagnetic signals in fiber optic technologies, including critical angle and total internal reflection.
Manufacturing			4.1 Manufacturing systems of custom and mass production. 4.2 Impacts of interchangeable parts, components of mass-produced products, and the use of automation. 4.3 Manufacturing organization. 4.4 Basic processes in manufacturing systems.	7.1 Manufacturing processes 7.2 Criteria necessary to select safe tools and procedures for the manufacturing process. 7.3 Advantages of using robotics in the automation of manufacturing processes.

Broad Topic	**Content of Each Learning Standard**			
	PreK–2	**Grades 3–5**	**Grades 6–8**	**High School**
Construction			5.1 Parts of a structure. 5.2 Three major types of bridges and their appropriate uses. 5.3 The forces of tension, compression, torsion, bending, and shear affect the performance of bridges. 5.4 Effects of load and structural shape on bridges.	2.1 Engineering properties of materials used in structures. 2.2 Differences between tension, compression, shear, and torsion, and how they relate to the selection of materials in structures. 2.3 Bernoulli's principle and its effect on structures. 2.4 Resultant force(s) for a combination of live and dead loads. 2.6 The purposes of zoning laws and building codes in the design and use of structures.
Transportation			6.1 Transportation systems and devices that operate on or in land, air, water, and space. 6.2 Possible solutions to transportation problems, using the universal systems model. 6.3 Three subsystems of a transportation vehicle or device. 6.4 Lift, drag, friction, thrust, and gravity in a vehicle or device.	
Bio-engineering			7.1 Adaptive and assistive devices. 7.2 Adaptive and assistive bioengineered products.	
Fluid Systems				3.1 Differences between open and closed fluid systems. 3.2 Hydraulic and pneumatic systems and how each relates to manufacturing and transportation systems. 3.3 The ability of a hydraulic system to multiply distance, multiply force, and effect directional change. 3.4 The velocity of a liquid moving in a pipe varies inversely with changes in the pipe's cross-sectional area. 3.5 Sources of resistance for water moving through a pipe.
Thermal Systems				4.1 Differences among conduction, convection, and radiation in a thermal system. 4.2 Conduction, convection, and radiation are considered in the selection of materials for buildings and in the design of a heating system. 4.3 Environmental conditions influence the design of buildings. 4.4 Alternatives to nonrenewable energies.
Electrical Systems				5.1 Measure and calculate voltage, current, resistance, and power consumption in series and parallel circuits. 5.2 Components of a circuit. 5.3 Relationships among voltage, current, and resistance in a simple circuit, using Ohm's law. 5.4 Resistance is affected by external factors. 5.5 Alternating current and direct current.

Appendix V
Dissection and Dissection Alternatives in Science Courses: Policies and Resources for Massachusetts Public Schools

Introduction

This Guidance Document (approved by the Board of Education, October 2005) is designed to assist district and school personnel in implementing the Board of Education's policy regarding dissection and dissection alternatives in science courses. This document also provides a variety of alternative resources to actual dissection.

State Policy

The Board of Education approved policy on dissection and dissection alternatives states:

> **All public schools that offer dissection as a learning activity should, upon written request by a student's parent or guardian, permit a student who chooses not to participate in dissection to demonstrate competency through an alternative method.**

Biology teachers consider dissection to be an important educational tool. But dissection should be used with care. When animal dissection is considered, teachers should recognize that there are other experiences (e.g., computer programs) for students who choose not to participate in actual dissections.

Further, as described in Massachusetts G.L. Chapter 272, 80G, and in Appendix IV, dissection should be confined to the classroom: "Dissection of dead animals or any portions thereof in . . . schools shall be confined to the classroom and to the presence of pupils engaged in the study to be promoted thereby and shall in no case be for the purpose of exhibition." This law covers treatment of animals in school settings (not just dissection). Please refer to Appendix IV for further information concerning the treatment of animals and dissection in the classroom.

Recommendations for School and Districts

#1: Schools should be responsible about both the use of live animals and dissection of dead animals in the classroom.

Schools and school districts should ensure that animals are properly cared for and treated humanely, responsibly, and ethically. The National Science Teachers Association's recommendations on how to include live animals and dissection of dead animals in the classroom can be found at http://www.nsta.org/positionstatement&psid=44&print=y.

#2: Schools should develop clear policies on dissection and dissection alternative activities.

Schools and school districts should establish a written policy on courses that include animal dissection. The school policy should state that options are available for students who object to dissection activities and that, upon written request by a student's parent or guardian, the school will permit a student who objects to dissection activities to demonstrate competency through an alternative method. The policy should specify the alternatives to dissection that are available to the student, and explain how a student may participate in an alternative to dissection upon written request of the student's parent or guardian.

The teacher (or other school authority) should specify in writing what is expected of the student participating in an alternative activity. Alternative activities should allow students to gain the same content knowledge as a dissection activity and should allow for a comparable investment of time and effort by the student. Students participating in the alternative project should be subject to the same course standards and examinations as other students in the course.

The school's policy on dissection and dissection alternatives should be included in the student handbook. The school should also provide a copy of the policy at the beginning of the school year to all teachers of science courses that involve dissection. A sample school policy and sample form letter for parents/guardians are included at the end of this appendix.

#3: Schools should include information about dissection in relevant course descriptions, and should clearly specify dissection alternatives in that information.

When the school or school district publishes descriptions of the courses that it offers in the life sciences, the description for each course should specify whether dissection is part of the standard laboratory experience in that course. The course description should also state that alternatives to dissection are available for any student who objects to dissection and whose parent or guardian sends a written request to the school.

Information and Resources

1. Guidance and position statements from various science organizations

National Science Teachers Association. *Position Statement on Responsible Use of Live Animals and Dissection in the Science Classroom*. 2005.
http://www.nsta.org/positionstatement&psid=44&print=y.

Institute of Laboratory Animal Resources, Institute of Medicine, National Research Council, National Academy of Sciences, National Academy of Engineering. Principles and Guidelines for the Use of Animals in Precollege Education. 2006.
http://dels.nas.edu/ilar_n/ilarhome/Principles_and_Guidelines.pdf

National Association of Biology Teachers. *Position Statement on the Use of Animals in Biology Education*. 2003.
http://www.nabt.org/sub/position_statements/animals.asp

2. Resources on alternatives to dissection

A number of organizations will loan alternatives, such as CD-ROMs (virtual dissections), models, and videos to students and schools. The following organizations have free lending libraries and will help teachers find a suitable alternative to a dissection activity. (Note: Often a security deposit is required but no charges are incurred unless the items are not returned or are returned damaged. The borrower is responsible for return shipping.)

The American Anti-Vivisection Society (AAVS)
1-800-729-2287
www.animalearn.org

The Ethical Science and Education Coalition (ESEC)
617-523-6020
http://www.neavs.org/resources/index.htm

(This is a Boston-based organization that can provide teacher training.)

The Humane Society of the United States (HSUS)
301-258-3042
http://www.hsus.org/animals_in_research/animals_in_education/humane_education_loan_program_help/materials_available_through_help.html

The National Anti-Vivisection Society (NAVS)
1-800-888-6287
Dissection Alternative Loan Program
http://www.navs.org/site/PageServer?pagename=ain_edu_dissection_loan_program

The following websites offer free alternatives to dissection:

- Interactive Frog Dissection: An Online Tutorial (http://curry.edschool.virginia.edu/go/frog/)
- Kidwings: Virtual Owl Pellet Dissection (http://www.kidwings.com)
- Virtual Dissection Site: Crayfish, Earthworm, Squid, Frog (http://biology.about.com/cs/dissections/%0D)
- Virtual Frog Dissection Kit (http://froggy.lbl.gov/)
- Virtual Pig Dissection (VPD) (http://www.whitman.edu/biology/vpd/)
- Anatomically Correct: The Online Cat Dissection (http://library.thinkquest.org/15401/learn.html)
- Exploratorium's Cow's Eye Dissection (http://www.exploratorium.edu/learning_studio/cow_eye/index.html)
- The Crayfish Corner (http://www.mackers.com/crayfish/)
- Dissection of a Deer Tick (http://www.ent.iastate.edu/imagegal/ticks/iscap/tickdissection/)
- The Heart: An Online Exploration (http://sln.fi.edu/biosci/heart.html)
- University of Scranton's Dissection of the Sheep Brain (http://academic.uofs.edu/department/psych/sheep/ieframerow.html)
- Exploratorium's Sheep Brain Dissection: The Anatomy of Memory (http://www.exploratorium.edu./memory/braindissection/index.html)

The websites below list numerous dissection alternatives but are intended for information only. Teachers who identify an item on one of these databases that they want to borrow or purchase should contact the free lending libraries listed above.

- Norina (http://oslovet.veths.no/NORINA/)
- InterNICHE (http://www.interniche.org/alt.html - alt)
- The Physicians Committee for Responsible Medicine (http://www.pcrm.org/)
- Alternatives in Education Database (http://avar.org/alted_database.html)

A special thanks to the New England Anti-Vivisection Society (www.neavs.org) and TEACHkind (www.teachkind.org/) for providing input to this list of dissection alternative resources.

3. Sample School Policy and Sample Form Letter for Parents/Guardians

A sample school policy and a sample form letter for parents/guardians are provided on the following pages.

SAMPLE SCHOOL POLICY

POLICY ON DISSECTION AND DISSECTION ALTERNATIVES

In accordance with the 2005 Board of Education's Policy on Dissection and Dissection Alternatives, our School/School District has developed the following policy.

Participation in hands-on science is important to learning science, and dissections are a valuable learning experience in which all students are encouraged to participate. When dissection is used in the classroom:

- Teachers will thoroughly explain the learning objectives of the lesson and use written and audio-visual materials, as appropriate, to maximize the educational benefits of the experience.
- All specimens will be treated with respect.
- All students will be informed, prior to the dissection, that they have the option of discussing individual concerns about dissection with the appropriate teacher.
- Upon completion of the dissection, the remains will be appropriately disposed of as recommended by the local board of public health.

The science courses that include dissection also offer dissection alternatives. Upon written request of a student's parent or guardian, our school will permit a student who objects to dissection activities to demonstrate competency through an alternative method.

Currently our school offers the following courses that include dissection: (*name courses, such as: Biology, Honors Biology, and Anatomy and Physiology)*. Specific dissection and dissection alternative activities will be listed on the course syllabi, available to students before enrolling in these courses.

Alternative activities may include: models (*name models*) and Internet programs (*name programs*) in place of dissecting (*name organism*).

(Note: Schools may find it easier to provide a chart such as the one below.)

Course	Dissection Activity	Dissection Alternative Activity

The procedure for a student to participate in an alternative activity in place of dissection is as follows:

- The student will notify the science teacher of the student's choice to participate in an alternative activity in place of participating in a dissection.
- The student will submit a written request from his or her parent/legal guardian to the science teacher or to the school principal.

- The student will be provided an alternative activity to be determined by the teacher, who will specify in writing what is expected of the student. Alternative activities will allow students to gain the same content knowledge as the dissection activities and will require a comparable investment of time and effort by the student.

- The student will accept responsibility for completing the alternative activity within the assigned time and is expected to learn the same content knowledge as if the student were performing the dissection activity.

- The student will be subject to the same course standards and examinations as other students in the course.

This policy is included in the student handbook and is also provided at the beginning of each school year to all teachers of science courses that involve dissection.

SAMPLE PARENT/GUARDIAN FORM LETTER

Note: A student's parent/guardian is not required to use a particular form to request that the school provide the student with an alternative to dissection. This sample is provided for the convenience of school personnel and parents/guardians who wish to use it.

Dear _____________________________(Principal or Teacher):

I understand that participation in hands-on science is important to learning science and that dissections are an important component of comprehensive science and life science education. I also understand that alternatives to dissection are available and that, upon written request of a parent/legal guardian, the school will permit a student to demonstrate competency through an alternative method, such as computer simulations and other appropriate research activities. I further understand that students participating in alternative activities instead of dissection are subject to the same course standards and examinations as other students in the course.

I request that my child, ___________________________________, be permitted to demonstrate competency through alternative activities rather than participating in dissection.

Sincerely,

____
Signature of parent or legal guardian

____
Printed name of parent or legal guardian

Date:____________________________

Curriculum Review Resources

Several organizations have conducted textbook and/or curricular reviews of a range of materials available for science and technology/engineering classrooms. Each organization generally uses a consistent rubric in their review to highlight the features and design of each text or curriculum. Below are links to two organizations that have completed reviews of science texts and/or curricula.

Education Development Center, Inc. (EDC)
Curriculum Profiles
http://cse.edc.org/work/k12dissem/materials.asp

American Association for the Advancement of Science (AAAS)
Project 2061 Textbook Evaluations
http://www.project2061.org/publications/textbook/default.htm