



Massachusetts Science and Technology/Engineering Curriculum Framework

October 2006

Pre-Kindergarten–High School Standards
as adopted by the Board of Education in 2001 (PreK–8) and 2006 (High School)
and
Updated Resources

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Commissioner's Foreword

Dear Colleagues,

I am pleased to present to you the 2006 updated *Massachusetts Science and Technology/Engineering Curriculum Framework*. This *Framework* articulates statewide guidelines for learning, teaching, and assessment in science and technology/engineering for the Commonwealth's public schools.

In June 2005, science and technology/engineering was added to the state's Competency Determination. We took this opportunity to clarify the high school standards and update the *Framework* text and resources. The PreK–8 standards have not changed in content from those presented in the 2001 *Framework*.

The 2006 updated *Framework* includes the following key changes:

- Revised high school standards approved by the Board of Education in January 2006, which include:
 - Clear learning expectations for each course
 - Scientific Inquiry Skills standards, integrated into each course
 - Mathematical skills necessary for a solid understanding of each course
- Additional high school vignettes to illustrate standards-based classroom lessons
- Elimination of the two-year integrated science course in grades 9 and 10
- Minor edits for content accuracy to four PreK–8 standards
- A new Guiding Principle discussing the importance of literacy skills in learning content
- Inclusion of the October 2005 Alternative Dissection Policy and related resources
- Reformatting of the Broad Topics appendix to facilitate curriculum alignment
- Expansion of the safety and legal appendix to highlight regulations applicable to science and technology/engineering classrooms
- Edits of the *Framework* text to assure coherence and flow throughout the document

I believe a strong understanding of science and technology/engineering is important for every student in the Commonwealth. Any student's ability to effectively contribute to her or his community is greatly enhanced by achieving proficiency in these areas. The Commonwealth's economy and continued quality of life depends on our ability to recruit students into these fields.

We will continue to work with schools and districts to implement the elements of this *Framework* and actively engage students in science and technology/engineering learning in the classroom. Thank you for your ongoing support and for your commitment to achieving the goals of education reform.

Sincerely,

David P. Driscoll
Commissioner of Education

Acknowledgments

The 2006 *Massachusetts Science and Technology/Engineering Curriculum Framework* is the result of the contributions of many educators across the state to the 2001 *Framework* and, more recently, to the 2006 revision of the high school standards. Because of the broad-based, participatory nature of the revision process, this document cannot reflect all of the professional views of every contributor. It reflects instead a balanced synthesis of their suggestions. The Department of Education wishes to thank all of the groups that contributed to the development of these science and technology/engineering standards: the Science and Technology/Engineering Revision Panel; the Mathematics/Science Advisory Council; the Technology/Engineering Advisory Council; grade-span teacher groups; professional educational associations and organizations; and all of the individual teachers, administrators, scientists, engineers, science education faculty, and parents who took the time to provide thoughtful comments during the public comment period.

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The *Massachusetts Science and Technology/Engineering Curriculum Framework* is available online at the Department's website (www.doe.mass.edu/frameworks/current.html). The downloadable files are the same as this printed version. Feedback, comments, or questions are welcome. Please contact the Office of Mathematics, Science, and Technology/Engineering at mathsciencetech@doe.mass.edu or (781) 338-3456.

Organization of the Framework

Organization of the Framework

This 2006 *Massachusetts Science and Technology/Engineering Curriculum Framework* provides a guide for teachers and curriculum coordinators regarding specific content to be taught from PreK through high school. Following this *Organization* chapter, the *Framework* contains the following sections:

Philosophy and Vision

The *Philosophy and Vision* chapter of the document provides general information in the following areas:

- The *Purpose and Nature of Science and Technology/Engineering* section describes how science and technology/engineering interrelate.
- The *Inquiry, Experimentation, and Design in the Classroom* section describes inquiry-based instruction and lists inquiry skills.
- The *Guiding Principles* articulate ideals of teaching, learning, assessing, and administering science and technology/engineering programs.

Science and Technology/Engineering Learning Standards

After a brief history of how the learning standards in Massachusetts were developed, the standards are presented by strand, grade span, and subject area topic.

The Strands

The learning standards are grouped into four strands:

- Earth and Space Science
- Life Science (Biology)
- Physical Sciences (Chemistry and Physics)
- Technology/Engineering

Each strand section begins with an overview of the strand.

Grade Spans and Subject Area Topics

Each strand's learning standards are grouped into four grade spans:

- Grades PreK–2
- Grades 3–5
- Grades 6–8
- High School

Learning standards are sub-grouped within each grade span under subject area topic headings that are specific to that grade span.

Grade PreK through Grade 8

Learning standards for grades PreK–8 are presented in tables that include ideas for grade-appropriate classroom investigations and learning experiences for each standard.

At grades PreK–2 and 3–5, for all strands except Technology/Engineering, these tables also include suggestions for related learning experiences in technology/engineering, and reference the PreK through grade 5 Technology/Engineering learning standards. In the Technology/Engineering strand, the grades PreK–2 and 3–5 tables list learning standards only.

At grades 6–8, suggestions for learning experiences in technology/engineering are included in the table with the grades 6–8 Technology/Engineering learning standards.

At least one detailed vignette is provided within most strands, titled “What It Looks Like in the Classroom,” to illustrate how to teach one or more grade-specific learning standards within that strand. Additional activities to illustrate and teach the grade PreK through grade 8 learning standards are suggested in Appendix II.

High School Introductory Courses

The 2006 revised high school learning standards listed in this *Framework* articulate the expectations for the following introductory courses:

- Earth and Space Science
- Biology (Life Science strand)
- Chemistry (Physical Sciences strand)
- Introductory Physics (Physical Sciences strand)
- Technology/Engineering

Within each high school course, two types of learning standards are provided:

- content standards in section I, summarized in one or more Central Concept statements, and further sub-grouped under subject area topic headings
- new Scientific Inquiry Skills (SIS) standards in section II

Section III of each course presents a list of mathematical skills students should have the opportunity to apply in that course.

A “What It Looks Like in the Classroom” vignette follows the mathematical skills section for most high school courses. For Technology/Engineering, additional suggested learning activities related to each subtopic are listed following the “What It Looks Like in the Classroom” pages.

Appendices

The following appendices provide curricular resources to support instruction at all grade levels:

- I. PreK through High School Learning Standards Organized by Strand and Broad Topics
- II. Additional Learning Activities for Grade PreK through Grade 8
- III. Historical and Social Context for Science and Technology/Engineering Topics for Study
- IV. Safety Practices and Legal Requirements
- V. Dissection and Dissection Alternatives in Science Courses: Policies and Resources for Massachusetts Public Schools
- VI. Curriculum Review Resources
- VII. Criteria for Evaluating Instructional Materials and Programs in Science and Technology/Engineering

References

The glossary, bibliography, and Web pages in the *Reference* section include selected resources for use in implementing this *Framework* effectively in the classroom.

Philosophy and Vision

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.

Grades PreK–2

- Ask questions about objects, organisms, and events in the environment.
- Tell about *why and what would happen if?*
- Make predictions based on observed patterns.
- Name and use simple equipment and tools (e.g., rulers, meter sticks, thermometers, hand lenses, and balances) to gather data and extend the senses.
- Record observations and data with pictures, numbers, or written statements.
- Discuss observations with others.

Grades 3–5

- Ask questions and make predictions that can be tested.
- Select and use appropriate tools and technology (e.g., calculators, computers, balances, scales, meter sticks, graduated cylinders) in order to extend observations.
- Keep accurate records while conducting simple investigations or experiments.
- Conduct multiple trials to test a prediction. Compare the result of an investigation or experiment with the prediction.
- Recognize simple patterns in data and use data to create a reasonable explanation for the results of an investigation or experiment.
- Record data and communicate findings to others using graphs, charts, maps, models, and oral and written reports.

Grades 6–8

- Formulate a testable hypothesis.
- Design and conduct an experiment specifying variables to be changed, controlled, and measured.
- Select appropriate tools and technology (e.g., calculators, computers, thermometers, meter sticks, balances, graduated cylinders, and microscopes), and make quantitative observations.
- Present and explain data and findings using multiple representations, including tables, graphs, mathematical and physical models, and demonstrations.
- Draw conclusions based on data or evidence presented in tables or graphs, and make inferences based on patterns or trends in the data.
- Communicate procedures and results using appropriate science and technology terminology.
- Offer explanations of procedures, and critique and revise them.

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.

*Science and Technology/Engineering
Learning Standards*

Science and Technology/Engineering Learning Standards

This *Massachusetts Science and Technology/Engineering Curriculum Framework* is one of seven curriculum frameworks that advance Massachusetts' educational reform in learning, teaching, and assessment. It was created and has been revised by teachers and administrators of science and technology/engineering programs in prekindergarten through grade 12 school districts, and by college and university professors, engineers, and scientists in the various domains, along with staff from the Department of Education.

Development of the Standards

1995, Initial Framework

This 2006 *Framework* derives from two reform initiatives in Massachusetts: the Education Reform Act of 1993, and Partnerships Advancing the Learning of Mathematics and Science (PALMS). From 1992 to 2002, the PALMS Statewide Systemic Initiative was funded by the National Science Foundation in partnership with the state and the Noyce Foundation. A central goal of these initiatives was to develop, disseminate, and implement curriculum frameworks in mathematics and in science and technology. The initial *Science and Technology Curriculum Framework* was approved in 1995, and was implemented in the field.

2001, Full Revision of the Framework

Because the Education Reform Act required that frameworks be reviewed and revised periodically, a revision panel was appointed by the Commissioner and the Board of Education in the summer of 1998. The panel examined the standards in the original *Science and Technology Curriculum Framework*, reviewed comments on them from the field, and reassessed their appropriateness in order to work out a more coherent organization of concepts and skills through the grade levels. The panel referred to the *Benchmarks for Science Literacy—Project 2061*, data from the Third International Mathematics and Science Study, the National Research Council's *National Science Education Standards*, the Technology for All Americans Project, results from the 1998 administration of the MCAS Science and Technology tests, and advances in science and technology/engineering.

The draft produced by the revision panel was released for public comment in August 1999. Based on comments on this draft from science and technology/engineering teachers and other educators, further revisions were made, particularly at the high school level. Groups of high school science teachers in each domain of science and technology/engineering developed a comprehensive set of standards for a course in each domain. The 2001 *Framework*, for the first time, articulated standards for full-year high school courses in earth and space science, biology, chemistry, introductory physics, and technology/ engineering. The *Framework* identified a subset of "core" standards for each course that were designed to serve as the basis for high school MCAS assessments. This version of the *Framework* was approved and implemented in May 2001.

2006, Revised High School Standards and Framework Update

Revised High School Standards

The revision of the high school standards in 2006 was undertaken in preparation for the inclusion of science and technology/engineering in the Competency Determination. In particular, the revision achieved two main objectives. One objective was to make all standards assessable by removing the identification of “core” standards. The second objective was to include standards that would promote the teaching and learning of science through laboratory experiences. The 2006 revised science and technology/engineering high school learning standards now list both the *science content knowledge* and *scientific inquiry skills* needed to achieve scientific literacy.

Each standard presents an expected measure of depth and specificity for a concept or topic. Teachers may choose to teach any of the standards in greater depth, or address topics that are not reflected in the standards. However, the amount of time taken to teach a topic beyond the stated standard should be balanced with the need to provide students an opportunity to effectively learn all the standards for a course.

Key revisions to the high school science and technology/engineering standards include the following:

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

Framework Update

The 2006 *Massachusetts Science and Technology/Engineering Curriculum Framework* includes the following key updates:

- Several Guiding Principles are revised, including additions regarding literacy (VI), high expectations (VII), assessment (VIII), and clarification of district-wide planning (X).
- The 2006 revised high school standards replace the 2001 high school standards.
- Additional vignettes at the high school level illustrate teaching and learning experiences.
- Appendix I relates learning standards across all grade spans to Broad Topics within each strand.
- Safety practices and legal regulations are detailed (Appendix IV).
- Appendix V presents the Department of Education’s (October 2005) Alternative Dissection Policy and resources.
- Links to curriculum reviews by other organizations are provided in Appendix VI.
- Web links are updated.

Please note that the grade PreK through grade 8 learning standards presented in this *Framework* have not changed from the content of the learning standards presented in the 2001 *Framework*. Minor edits, however, were made to four of the grades 3–8 standards to address content accuracy. These include: Earth and Space Science, 6-8, #2; and Technology/Engineering, 3-5, #1.1; and 6-8, #1.1 and 6.1.

Earth and Space Science

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.

- In **grades PreK–2**, students are naturally interested in everything around them. This curiosity leads them to observe, collect, and record information about the earth and about objects visible in the sky. Teachers should encourage their students’ observations without feeling compelled to offer precise scientific reasons for these phenomena. Young children bring these experiences to school and learn to extend and focus their explorations. In the process, they learn to work with tools like magnifiers and simple measuring devices.

Learning standards for grades PreK–2 fall under the following four subtopics: *Earth’s Materials*; *The Weather*; *The Sun as a Source of Light and Heat*; and *Periodic Phenomena*.

- In **grades 3–5**, students explore properties of geological materials and how they change. They conduct tests to classify materials by observed properties, make and record sequential observations, note patterns and variations, and look for factors that cause change. Students observe weather phenomena and describe them quantitatively using simple tools. They study the water cycle, including the forms and locations of water. The focus is on having students generate questions, investigate possible solutions, make predictions, and evaluate their conclusions.

Learning standards for grades 3–5 fall under the following six subtopics: *Rocks and Their Properties*; *Soil*; *Weather*; *The Water Cycle*; *Earth’s History*; and *The Earth in the Solar System*.

- In **grades 6–8**, students gain sophistication and experience in using models, satellite images, and maps to represent and interpret processes and features. In the early part of this grade span, students continue to investigate geological materials’ properties and methods of origin. As their experiments become more quantitative, students should begin to recognize that many of the earth’s natural events occur because of processes such as heat transfer.

Students in these grades should recognize the interacting nature of the earth’s four major systems: the geosphere, hydrosphere, atmosphere, and biosphere. They should begin to see how the earth’s movement affects both the living and nonliving components of the world. Attention shifts from the properties of particular objects toward an understanding of the place of the earth in the solar system and changes in the earth’s composition and topography over time. Middle school students grapple with the importance and methods of obtaining direct and indirect evidence to support current thinking. They recognize that new technologies and observations change our explanations about how things in the natural world behave.

Learning standards for grades 6–8 fall under the following five subtopics: *Mapping the Earth*; *Earth’s Structure*; *Heat Transfer in the Earth System*; *Earth’s History*; and *The Earth in the Solar System*.

- 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, Grades PreK–2

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES	SUGGESTED EXTENSIONS TO LEARNING IN TECHNOLOGY/ENGINEERING <small>(Technology/Engineering standards for grades PreK–2 are on page 85.)</small>
Earth's Materials		
1. Recognize that water, rocks, soil, and living organisms are found on the earth's surface.	Walk around the playground observing and discussing where water, rocks, soil, and living organisms are found.	<i>Identify characteristics shared by naturally occurring rocks and manmade concrete. (T/E 1.1)</i>
2. Understand that air is a mixture of gases that is all around us and that wind is moving air.	Use a hand pump to inflate a basketball. Observe and discuss how and why the basketball gets larger as more air is added. (Air takes up space.)	<i>Design a kite and identify which materials would be used for its construction. Classify them as natural or manmade materials. Build the kite and fly it outside. (T/E 1.1, 1.2)</i>
The Weather		
3. Describe the weather changes from day to day and over the seasons.	Keep a class weather chart indicating daily temperature, how windy it is, which direction wind is blowing (use visual clues), and kind of precipitation, if any.	<i>Design and build a tool that could be used to show wind direction (wind sock). (T/E 1.3)</i>
The Sun as a Source of Light and Heat		
4. Recognize that the sun supplies heat and light to the earth and is necessary for life.	Record the time of day when the sun shines in different school locations and note patterns.	<i>Design a shade for the window to keep the room cool in the summer or to keep the sun out for television viewing. (T/E 1.1, 1.3)</i>
Periodic Phenomena		
5. Identify some events around us that have repeating patterns, including the seasons of the year, day and night.	Make a list of things seen outdoors and in the sky during the day. Make another list of things seen outdoors and in the sky at night. Discuss the differences between the day and night lists.	<i>Use a thermometer to record the temperature from morning to noon over several weeks and discuss any patterns that emerge. (T/E 2.1)</i>

Earth and Space Science, Grades 3–5

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES	SUGGESTED EXTENSIONS TO LEARNING IN TECHNOLOGY/ENGINEERING <small>(Technology/Engineering standards for grades 3–5 are on page 86.)</small>
Rocks and Their Properties		
1. Give a simple explanation of what a mineral is and some examples, e.g., quartz, mica.	Observe and describe the characteristics of ore minerals such as magnetite and hematite (two sources of iron).	<i>Design a flowchart to demonstrate how silica from sand is used to make glass. (T/E 2.2)</i>
2. Identify the physical properties of minerals (hardness, color, luster, cleavage, and streak), and explain how minerals can be tested for these different physical properties.	Acquire a collection of minerals that includes (a) duplicates of the same mineral, somewhat different in appearance (size, shape, exact color) and (b) samples of minerals that look similar but are actually different. Examine minerals using a hand lens. Look for and record similarities and differences such as heaviness, color, texture, crystal shapes, luster, surface patterns, etc. Sort as accurately as possible. Report total number of different minerals present, and how many duplicates, if any, of each type.	<i>Use simple tools to test for hardness, e.g., Moh’s Scale of Hardness. (T/E 1.1)</i>
3. Identify the three categories of rocks (metamorphic, igneous, and sedimentary) based on how they are formed, and explain the natural and physical processes that create these rocks.	Examine rocks collected from the schoolyard or a field trip location, or brought in from home. Sort rocks into igneous, metamorphic, or sedimentary based on their physical properties.	<i>Discuss the use of rocks in construction based on their physical properties. Test the hardness of various types of rocks used in construction. (T/E 1.1)</i>
Soil		
4. Explain and give examples of the ways in which soil is formed (the weathering of rock by water and wind and from the decomposition of plant and animal remains).	Observe sand with a hand lens. Note how particles resemble minerals. Observe topsoil with a hand lens. Look for fragments of organisms. Note differences in color, texture, odor, and clumping due to organic components vs. pure sand. Mix topsoil and sand together in various proportions to represent samples of types of soils.	<i>Design and construct a composting bin being sure to keep design considerations in mind, e.g., aeration, resistance to rot, etc. (T/E 1.2, 2.1–2.3)</i>

Earth and Space Science, Grades 3–5

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES	SUGGESTED EXTENSIONS TO LEARNING IN TECHNOLOGY/ENGINEERING <small>(Technology/Engineering standards for grades 3–5 are on page 86.)</small>
Soil (cont.)		
<p>5. Recognize and discuss the different properties of soil, including color, texture (size of particles), the ability to retain water, and the ability to support the growth of plants.</p>	<p>Design an experiment to find out if different soil samples retain different amounts of water. Explain how the properties of the particles affect the large-scale properties of the soil like water retention and speed of water flow. Discuss how a soil’s water retention affects the animals and plants that live in it.</p>	<p><i>Use sieves of different mesh sizes to separate coarse and fine materials in a soil sample. Approximate the ratio of fine to coarse material in the sample. (T/E 1.1, 1.2)</i></p>
Weather		
<p>6. Explain how air temperature, moisture, wind speed and direction, and precipitation make up the weather in a particular place and time.</p>	<p>Use a collection of classical (not digital) weather instruments, including thermometer, barometer, rain gauge, hygrometer, and anemometer, that clearly show the physical principle that makes them work. Note: A “homemade” instrument is often too inaccurate and unreliable to be a good weather teaching aid by itself. However, when used in combination with a working instrument of similar simple design, it can help students grasp both an important physical concept and its relevance to weather.</p>	<ul style="list-style-type: none"> • <i>Using measuring tools or graph paper, sketch a scale drawing of the front view of an object used to measure weather. (T/E 2.3)</i> • <i>Design and construct a variety of simple instruments that could be used to measure weather. Discuss how their design suits their purpose. (T/E 2.1–2.4)</i> • <i>Explain how tools of technology such as a hammer, screwdriver, pliers, tape measure, screws, nails, and other mechanical fasteners can be used to make or build weather instruments. (T/E 1.1)</i>
<p>7. Distinguish among the various forms of precipitation (rain, snow, sleet, and hail), making connections to the weather in a particular place and time.</p>	<p>Measure various forms of precipitation. Bring a measured sample of snow into the classroom, allow it to melt, and compare the amount of water that results with the original measurement.</p>	<p><i>Construct various weather station instruments (e.g., wind gauge, barometer, anemometer), record data from them, and make conclusions. (T/E 1.1, 1.2, 2.1, 2.2, 2.3)</i></p>

Earth and Space Science, Grades 3–5

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES	SUGGESTED EXTENSIONS TO LEARNING IN TECHNOLOGY/ENGINEERING <small>(Technology/Engineering standards for grades 3–5 are on page 86.)</small>
Weather (cont.)		
8. Describe how global patterns such as the jet stream and water currents influence local weather in measurable terms such as temperature, wind direction and speed, and precipitation.	Design an activity to illustrate convection (essential in transferring both heat and moisture around the world; drives both wind circulation and ocean currents.) Freeze a dark solution of food coloring and water in an ice cube tray. Float a colored ice cube on water in a transparent container. Discuss what happens, and how it is connected to convection in both liquid and gas.	<i>Make a model of an ocean current. Fill a jar halfway with warm water. Sprinkle some pepper into the water to represent particles in the ocean. Put a colored ice cube into the jar. Draw and describe observations. (T/E 2.2)</i>
9. Differentiate between weather and climate.	Collect daily temperature and precipitation data, preferably by observation, at school. At the same time use the Internet or a newspaper to collect the same data for a nearby city and a city on the west coast of the U.S. After three months, take various averages of the daily data for the three locations. Graph the data. Discuss how the long-term daily weather averages begin to describe each climate.	<ul style="list-style-type: none"> • <i>Discuss tools used to measure everyday weather compared with tools used in determining climate. (T/E 1.2)</i> • <i>Use a thermometer and barometer to compare conditions indoors and outdoors. (T/E 2.4)</i>
The Water Cycle		
10. Describe how water on earth cycles in different forms and in different locations, including underground and in the atmosphere.	Draw a diagram of the water cycle. Label evaporation, condensation, and precipitation. Explain what happens during each process.	<i>Design and build a terrarium to demonstrate the water cycle. (T/E 1.2, 2.1–2.3)</i>
11. Give examples of how the cycling of water, both in and out of the atmosphere, has an effect on climate.		

Earth and Space Science, Grades 3–5

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES	SUGGESTED EXTENSIONS TO LEARNING IN TECHNOLOGY/ENGINEERING (Technology/Engineering standards for grades 3–5 are on page 86.)
Earth's History		
12. Give examples of how the surface of the earth changes due to slow processes such as erosion and weathering, and rapid processes such as landslides, volcanic eruptions, and earthquakes.	To demonstrate the influence of vegetation on erosion, put soil in two shallow rectangular baking pans. Cover one pan with a layer of sod. Elevate one end of each pan. Compare and discuss the erosion caused by equal amounts of water running down each slope.	<i>Identify one manmade attribute that slows the erosion process (e.g., hay bales used at a construction site, silt fence protecting sand dunes) and one attribute that accelerates it (e.g., paving a parking lot, cutting trees). Relate these to natural systems. (T/E 2.1, 2.4)</i>
The Earth in the Solar System		
13. Recognize that the earth is part of a system called the “solar system” that includes the sun (a star), planets, and many moons. The earth is the third planet from the sun in our solar system.	Create a proportional model of the solar system starting on the school playground and extending as far as possible. Demonstrate the size of objects (use a pea for the smallest planet, and different-sized balls for the others) and the distance between them.	
14. Recognize that the earth revolves around (orbits) the sun in a year’s time and that the earth rotates on its axis once approximately every 24 hours. Make connections between the rotation of the earth and day/night, and the apparent movement of the sun, moon, and stars across the sky.	Observe and discuss changes in length and direction of shadows during the course of a day.	<i>Design and build a sundial and use it to determine the time of day. Explore how accurate it is over time. Determine the conditions under which the sundial does and does not work. (T/E 1.1, 1.2, 2.3)</i>
15. Describe the changes that occur in the observable shape of the moon over the course of a month.	Observe the sky every night for 30 days. Record every night the shape of the moon and its relative location across the sky (record the date of the month and the time of observation each time as well).	<i>Design and create a calendar that illustrates the phases of the moon. (T/E 2.2, 2.3)</i>

Weather Stations

Adapted from the National Science Education Standards, pp. 131–133

Earth and Space Science, Grades 3–5

Soon after school opened in the fall, Mr. Shahan introduced the concept of a weather station. After a discussion of students' experiences with and ideas about weather, Mr. Shahan asked the class what kinds of information would be important to collect and how they might go about collecting it. The students quickly identified the need to record whether the day was sunny or cloudy, the presence of precipitation, and the temperature. Mr. Shahan asked some questions and the list became more complicated: What kinds of clouds were evident? How much precipitation accumulated? How did the temperature change day to day and over the course of a given day? What was the wind speed and direction? One student said that she heard there was a high-pressure front moving in. "What is a front," she asked, "and is it important?" At the end of the discussion, someone mentioned humidity and recalled the muggy heat wave of the summer.

The class spent time discussing and planning how they were going to measure the weather conditions, what tools they would need, and how they would collect and analyze the data. Students worked in groups, and each group focused on one aspect of weather. Twice each week, the groups shared their work with the whole class.

Several weeks later, the weather station that the students had created was in operation, and they recorded data twice a day. The class made an anemometer and a wind vane and used them to observe wind direction and speed. They used a commercial thermometer to observe temperature, and a commercial rain gauge to observe precipitation. They measured the air pressure with a handmade barometer that a parent helped one student group construct. The class relied on their visual observations to keep a record of cloud formations.

After two months, it was time for each group to analyze the data and write the first report for the class weather book. The class discussed their ideas and raised the following questions for further study: Is the temperature getting lower? What is the relationship between the direction of the wind and the weather the following day? What happens when the air pressure goes down or up? Was it colder when it was cloudy?

One group created a bar graph that showed the total number of sunny, cloudy, and rainy days. Another group made a graph that showed the daily temperature fluctuations and demonstrated that the weather was definitely getting colder. Still another team made an interesting table that illustrated that when the air pressure dropped, the weather usually seemed to get worse.

Midyear, Mr. Shahan was satisfied that the students understood the use of charts and graphs, and he introduced a simple computer program that allowed the students to record their data more easily. The class operated the weather station all year and analyzed the data approximately every two months. At the end of the school year, the class donated its weather book to the school library to be used as a reference by other students.

Through this extended exercise, the students learned how to ask questions, create tools to gather data, and collect and organize data. Specifically, they learned how to describe daily weather changes in terms of temperature, wind speed and direction, precipitation, and humidity.

WHAT IT LOOKS LIKE IN THE CLASSROOM

Assessment Strategies

- Discuss with the class the learning objectives for this unit. Develop a rubric for group work and written reports.
- Students can keep a weather record book in which they record notes, observations, and data. Periodically throughout the unit, these books can be reviewed and graded by the teacher, and used to assess what skills or concepts the students understand and to identify the skill areas that need further instruction. Personalized notes to students in their books can individualize instruction by suggesting particular activities or resources that will further the students' learning.
- Students can measure the effectiveness and accuracy of their homemade instruments by comparing the data collected with them to data measured using commercial instruments.

Earth and Space Science Learning Standards

Grades 3–5

6. Explain how air temperature, moisture, wind speed and direction, and precipitation make up the weather in a particular place and time.
7. Distinguish among the various forms of precipitation (rain, snow, sleet, and hail), making connections to the weather in a particular place and time.
8. Describe how global patterns such as the jet stream and water currents influence local weather in measurable terms such as temperature, wind direction and speed, and precipitation.
9. Differentiate between weather and climate.

Technology/Engineering Learning Standards

Grades 3–5

- 1.1 Identify materials used to accomplish a design task based on a specific property, e.g., strength, hardness, and flexibility.
- 1.2 Identify and explain the appropriate materials and tools (e.g., hammer, screwdriver, pliers, tape measure, screws, nails, and other mechanical fasteners) to construct a given prototype safely.
- 2.3 Identify relevant design features (e.g., size, shape, weight) for building a prototype of a solution to a given problem.

Earth and Space Science, Grades 6–8

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES
Mapping the Earth	
1. Recognize, interpret, and be able to create models of the earth’s common physical features in various mapping representations, including contour maps.	Choose a small area of unpaved, sloping ground in the schoolyard or a park. Create a scale contour map of the area. Include true north and magnetic north.
Earth’s Structure	
2. Describe the layers of the earth, including the lithosphere, the hot convecting mantle, and the dense metallic core.	Use a Styrofoam ball and paint to construct a cross-section model of the earth.
Heat Transfer in the Earth System	
3. Differentiate among radiation, conduction, and convection, the three mechanisms by which heat is transferred through the earth’s system.	Investigate the movement of a drop of food coloring placed in water, with and without a heat source, and in different positions relative to a heat source.
4. Explain the relationship among the energy provided by the sun, the global patterns of atmospheric movement, and the temperature differences among water, land, and atmosphere.	Note the relationship between global wind patterns and ocean current patterns.
Earth’s History	
5. Describe how the movement of the earth’s crustal plates causes both slow changes in the earth’s surface (e.g., formation of mountains and ocean basins) and rapid ones (e.g., volcanic eruptions and earthquakes).	<ul style="list-style-type: none"> • Use the Pangaea map to understand plate movement. • Research and map the location of volcanic or earthquake activity. Relate these locations to the locations of the earth’s tectonic plates.
6. Describe and give examples of ways in which the earth’s surface is built up and torn down by natural processes, including deposition of sediments, rock formation, erosion, and weathering.	<ul style="list-style-type: none"> • Observe signs of erosion and weathering in local habitats and note seasonal changes. • Visit local sites following storm events and observe changes.

Earth and Space Science, Grades 6–8

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES
Earth's History (cont.)	
7. Explain and give examples of how physical evidence, such as fossils and surface features of glaciation, supports theories that the earth has evolved over geologic time.	Make a timeline showing index fossils. Discuss which of these fossils are actually found in New England. Discuss why some may be missing from local rocks.
The Earth in the Solar System	
8. Recognize that gravity is a force that pulls all things on and near the earth toward the center of the earth. Gravity plays a major role in the formation of the planets, stars, and solar system and in determining their motions.	Observe the speed at which objects of various mass drop from a common height. Use a chronometer to accurately measure time and plot the data as mass versus time necessary to reach the ground.
9. Describe lunar and solar eclipses, the observed moon phases, and tides. Relate them to the relative positions of the earth, moon, and sun.	Use globes and a light source to explain why high tides on two successive mornings are typically about 25 hours (rather than 24) apart.
10. Compare and contrast properties and conditions of objects in the solar system (i.e., sun, planets, and moons) to those on Earth (i.e., gravitational force, distance from the sun, speed, movement, temperature, and atmospheric conditions).	Using light objects such as balloons or basketballs, and heavy objects such as rocks, make models that show how heavy a 1 kg pumpkin would seem on the surfaces of the moon, Mars, Earth, and Jupiter.
11. Explain how the tilt of the earth and its revolution around the sun result in an uneven heating of the earth, which in turn causes the seasons.	
12. Recognize that the universe contains many billions of galaxies, and that each galaxy contains many billions of stars.	Count the number of stars that can be seen with the naked eye in a small group such as the Pleiades. Repeat with low-power binoculars. Repeat again with telescope or powerful binoculars. Research the number of stars present. Discuss the meaning of the research and its results.

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.

Earth and Space Science, High School

Learning Standards for a Full First-Year Course

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.

Earth and Space Science, High School

Learning Standards for a Full First-Year Course

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.

Earth and Space Science, High School

Learning Standards for a Full First-Year Course

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 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.

Life Science (Biology)

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.

- As Piaget noted, young children tend to describe anything that moves as *alive*. For purposes of working with students in **grades PreK–2**, who do not yet understand the continuity of life (e.g., from seed to seedling to tree to log), *living* can be defined as anything that is alive or has ever been alive (e.g., muskrat, flower, roadkill, log) and *nonliving* can be defined as anything that is not now and has never been alive (e.g., rock, mountain, glass, wristwatch). Over time, students refine their intuitive understanding. They begin to include in their definition of *living* such behaviors as eating, growing, and reproducing. They learn to use their senses to observe and then describe the natural world. Noticing differences and similarities, and grouping organisms based on common features are skills developed in the life science curriculum at this grade span. For a more in-depth discussion of this issue, please refer to the *National Science Education Standards*.

Learning standards for PreK–2 fall under the following four subtopics: *Characteristics of Living Things; Heredity; Evolution and Biodiversity; and Living Things and Their Environment*.

- In **grades 3–5**, students expand the range of observations they make of the living world. In particular, students in these grades record details of the life cycles of plants and animals, and explore how organisms are adapted to their habitats. Students move beyond using their senses to gather information. They begin to use measuring devices to gather quantitative data that they record, examine, interpret, and communicate. They are introduced to the power of empirical evidence as they design ways of exploring questions that arise from their observations.

Learning standards for grades 3–5 fall under the following four subtopics: *Characteristics of Plants and Animals; Structures and Functions; Adaptations of Living Things; and Energy and Living Things*.

- In **grades 6–8**, the emphasis changes from observation and description of individual organisms to the development of a more connected view of biological systems. Students in these grades begin to study biology at the microscopic level, without delving into the biochemistry of cells. They learn that organisms are composed of cells and that some organisms are unicellular and must therefore carry out all of the necessary processes for life within that single cell. Other organisms, including human beings, are multicellular, with cells working together. Students should observe that the cells of a multicellular organism can be physically very different from each other,

and should relate that fact to the specific role that each cell has in the organism (specialization). For example, cells of the eye or the skin or the tongue look different and do different things. Students in these grades also examine the hierarchical organization of multicellular organisms and the roles and relationships that organisms occupy in an ecosystem. As is outlined in the *National Science Education Standards*, students in grades 6–8 should be exposed in a general way to the systems of the human body, but are not expected to develop a detailed understanding at this grade level. They should develop the understanding that the human body has organs, each of which has a specific function of its own, and that these organs together create systems that interact with each other to maintain life.

At the macroscopic level, students focus on the interactions that occur within ecosystems. They explore the interdependence of living things, specifically the dependence of life on photosynthetic organisms such as plants, which in turn depend upon the sun as their source of energy. Students use mathematics to calculate rates of growth, derive averages and ranges, and represent data graphically to describe and interpret ecological concepts.

Learning standards for grades 6–8 fall under the following eight subtopics: *Classification of Organisms; Structure and Function of Cells; Systems in Living Things; Reproduction and Heredity; Evolution and Biodiversity; Living Things and Their Environment; Energy and Living Things; and Changes in Ecosystems Over Time.*

- 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.

Life Science (Biology), Grades PreK–2

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES	SUGGESTED EXTENSIONS TO LEARNING IN TECHNOLOGY/ENGINEERING <small>(Technology/Engineering standards for grades PreK–2 are on page 85.)</small>
Characteristics of Living Things		
1. Recognize that animals (including humans) and plants are living things that grow, reproduce, and need food, air, and water.	Draw and record the growth of a plant grown from seeds with different light exposures (vary the duration and intensity of light exposure).	<i>Design and construct a habitat for a living organism that meets its needs for food, air, and water. (T/E 1.1, 1.2, 1.3)</i>
2. Differentiate between living and nonliving things. Group both living and nonliving things according to the characteristics that they share.	Compare and contrast groups of animals (e.g., insects, birds, fish, mammals) and look at how animals in these groups are more similar to one another than to animals in other groups.	
3. Recognize that plants and animals have life cycles, and that life cycles vary for different living things.	<ul style="list-style-type: none"> • Using either live organisms or pictures/models, observe the changes in form that occur during the life cycle of a butterfly or frog. • Discuss the life cycle of a tree. 	<i>Design and build a habitat for a living organism that can be modified to meet the changing needs of the organism during its life cycle. (T/E 1.1, 1.2)</i>
Heredity		
4. Describe ways in which many plants and animals closely resemble their parents in observed appearance.	Look at and discuss pictures of animals from the same species. Observe and discuss how they are alike and how they are different.	
Evolution and Biodiversity		
5. Recognize that fossils provide us with information about living things that inhabited the earth years ago.	Look at a variety of fossils or pictures of fossils, including plants, fish, and extinct species. Guess what living organisms they might be related to.	<i>Make a fossil print of plant leaves using clay or putty. (T/E 1.1, 1.2)</i>

Life Science (Biology), Grades PreK–2

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES	SUGGESTED EXTENSIONS TO LEARNING IN TECHNOLOGY/ENGINEERING <small>(Technology/Engineering standards for grades PreK–2 are on page 85.)</small>
Living Things and Their Environment		
6. Recognize that people and other animals interact with the environment through their senses of sight, hearing, touch, smell, and taste.	<ul style="list-style-type: none"> • Observe small animals in the classroom while they find food, water, shelter, etc. • Talk about how people use their senses every day. 	<i>Design and build an ant farm. Observe how ants use their senses and how they communicate to each other the location of a food source. (T/E 1.1, 1.2, 1.3)</i>
7. Recognize changes in appearance that animals and plants go through as the seasons change.	Observe and record changes in plants (e.g., trees, flowers, grass) on the playground and around the school during fall, winter, and spring.	<i>Visit a maple syrup manufacturing facility. Discuss the sap-to-maple syrup process and the seasonal life cycle of a tree. (T/E 1.1, 1.2)</i>
8. Identify the ways in which an organism's habitat provides for its basic needs (plants require air, water, nutrients, and light; animals require food, water, air, and shelter).	Create a garden habitat that will attract and provide shelter for birds and butterflies. Research and plant appropriate flowers.	<i>Have students draw pictures of their houses and an animal's habitat. Discuss differences and similarities (e.g., type of materials used to build each shelter). (T/E 1.3)</i>

Life Science (Biology), Grades 3–5

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES	SUGGESTED EXTENSIONS TO LEARNING IN TECHNOLOGY/ENGINEERING <small>(Technology/Engineering standards for grades 3–5 are on page 86.)</small>
Characteristics of Plants and Animals		
1. Classify plants and animals according to the physical characteristics that they share.	<ul style="list-style-type: none"> • Sort plant and animal pictures based on physical characteristics. • Use a dichotomous key to identify plants. 	<i>Create a simple chart to classify plants and animals that are common to the school's geographical area. (T/E 2.2)</i>
Structures and Functions		
2. Identify the structures in plants (leaves, roots, flowers, stem, bark, wood) that are responsible for food production, support, water transport, reproduction, growth, and protection.	<ul style="list-style-type: none"> • Observe plant/pollinator interaction and seed dispersal methods. • Study maple trees and go maple sugaring. Identify the structures in the maple tree and their functions. 	<i>Collect plants. Make a detailed drawing of a plant. Identify and label its major structures (i.e., leaves, flowers, stems, roots, seeds). Describe the function of each structure. (T/E 2.2, 2.3)</i>
3. Recognize that plants and animals go through predictable life cycles that include birth, growth, development, reproduction, and death.	Grow plants from seed. Document the complete life cycle of the plant. Describe emergence of structures and the functions of these structures. Record changes in height over time. Graph the data.	<i>Design and construct a habitat for a small animal (e.g., insect, butterfly, frog) that has adequate space and contains the necessities for survival. The habitat should allow for observation of the animal as it goes through the stages of its life cycle. (T/E 1.1, 1.2, 2.1, 2.2, 2.3)</i>
4. Describe the major stages that characterize the life cycle of the frog and butterfly as they go through metamorphosis.	Using either live organisms or pictures/models, observe the changes in form that occur during the life cycle of a butterfly or frog.	

Life Science (Biology), Grades 3–5

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES	SUGGESTED EXTENSIONS TO LEARNING IN TECHNOLOGY/ENGINEERING <small>(Technology/Engineering standards for grades 3–5 are on page 86.)</small>
Structures and Functions (cont.)		
<p>5. Differentiate between observed characteristics of plants and animals that are fully inherited (e.g., color of flower, shape of leaves, color of eyes, number of appendages) and characteristics that are affected by the climate or environment (e.g., browning of leaves due to too much sun, language spoken).</p>	<p>Make frequency tables of the number of students with certain inherited physical traits, e.g., eye color, hair color, earlobe free or attached.</p>	
Adaptations of Living Things		
<p>6. Give examples of how inherited characteristics may change over time as adaptations to changes in the environment that enable organisms to survive, e.g., shape of beak or feet, placement of eyes on head, length of neck, shape of teeth, color.</p>	<p>Compare and contrast the physical characteristics of plants or animals from widely different environments (e.g., desert vs. tropical plants, aquatic vs. terrestrial animals). Explore how each is adapted to its environment.</p>	<p><i>Discuss how engineers design things by using their knowledge of the ways that animals move (e.g., birds and wings influence airplane design, tails and fins of aquatic animals influence boat design). (T/E 2.4)</i></p>
<p>7. Give examples of how changes in the environment (drought, cold) have caused some plants and animals to die or move to new locations (migration).</p>	<p>Investigate how invasive species out-compete native plants (e.g., phragmites and purple loosestrife). Discuss how some native plants die as a result.</p>	

Life Science (Biology), Grades 3–5

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES	SUGGESTED EXTENSIONS TO LEARNING IN TECHNOLOGY/ENGINEERING <small>(Technology/Engineering standards for grades 3–5 are on page 86.)</small>
Adaptations of Living Things (cont.)		
<p>8. Describe how organisms meet some of their needs in an environment by using behaviors (patterns of activities) in response to information (stimuli) received from the environment. Recognize that some animal behaviors are instinctive (e.g., turtles burying their eggs), and others are learned (e.g., humans building fires for warmth, chimpanzees learning how to use tools).</p>	<ul style="list-style-type: none"> • Discuss how newly born sea turtles find their way to the ocean. • Discuss how pets are trained to learn new tricks. • Discuss how migrating birds navigate. • Discuss the actions that coastal species take to adjust to the changing levels of the tide. • Observe an earthworm placed on top of soil in a container that is exposed to light. Discuss how its ability to sense light helps it survive (by burrowing) and how its structure allows it to burrow through soil. 	
<p>9. Recognize plant behaviors, such as the way seedlings' stems grow toward light and their roots grow downward in response to gravity. Recognize that many plants and animals can survive harsh environments because of seasonal behaviors, e.g., in winter, some trees shed leaves, some animals hibernate, and other animals migrate.</p>	<p>Set a germinating bean in a glass filled with water next to an asymmetric source of light. Allow the root and stem to grow a few inches. Rotate the bean so that the roots are now touching the water at an angle and the stem is away from the light source. Observe how the root system and stem respond to this change by changing their direction of growth.</p>	
<p>10. Give examples of how organisms can cause changes in their environment to ensure survival. Explain how some of these changes may affect the ecosystem.</p>	<ul style="list-style-type: none"> • Discuss the importance of wetlands to human survival. • Investigate how an invasive species changes an ecosystem. • Research local projects where humans are changing the environment to ensure a species' survival. 	<p><i>Brainstorm and sketch items in the home that do help or could help humans survive (e.g., heater for warmth, stove to cook). (T/E 2.1, 2.2)</i></p>

Life Science (Biology), Grades 3–5

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES	SUGGESTED EXTENSIONS TO LEARNING IN TECHNOLOGY/ENGINEERING <small>(Technology/Engineering standards for grades 3–5 are on page 86.)</small>
Energy and Living Things		
<p>11. Describe how energy derived from the sun is used by plants to produce sugars (photosynthesis) and is transferred within a food chain from producers (plants) to consumers to decomposers.</p>	<p>Make a food chain. Begin with the sun as the source of energy and end with decomposers. Create links that show the relationships of plants and animals in the chain. Show the direction of the flow of energy. Discuss results if various links in the chain are broken.</p>	<p><i>Design and build a compost bin. Use a thermometer to measure the temperature rise during composting. Discuss where heat (energy) comes from (decomposers metabolize energy stored by producers and consumers). (T/E 1.2)</i></p>

WHAT IT LOOKS LIKE IN THE CLASSROOM

Organisms in Their Environments

Adapted from a submission by Ellie Horowitz, Massachusetts Division of Fisheries and Wildlife

Life Science, Grades 3–5 (this activity can be adapted for other grade levels)

Every year, third-grade teacher Ms. Trestin does a unit on living things called “Life in the Soil.” On a trip to a wooded area or in the schoolyard, students look for living and nonliving things. Students often discover plants and animals, including insects, bugs, and other creatures living in and around leaf litter, rotting logs, or even behind plastic or wood in paved areas. As students observe these creatures, Ms. Trestin asks them, “What does it look like, and what is it doing?” She asks the students to identify, classify, catalog, and place in a food web the living organisms that they find. They develop field guides to the creatures of the different microhabitats.

Ms. Trestin extends this unit by examining life in fresh water. Students visit a pond or stream, wade into the shallow water, and slide a dip net along the bottom. The creatures they catch are placed carefully in small containers and observed with a hand lens. The students compare the similarities and differences among the creatures found in water and in soil.

Biodiversity Days, Any Grade Level

As an extension to the study of plants and animals, students at any grade level can participate in Biodiversity Days, which offers the community an opportunity to see how many species they can find in their area. Field guides or lists can be provided for the event. Students, teachers, and community members can investigate their schoolyards or recreation areas, or join a townwide effort. Students make lists of the common plants and animals, and then look closely to find ones that are different. A group of students may compile a list of everything they find, or may focus on a single group like birds, reptiles, amphibians, or animals that live in or around vernal pools. Class members may want to combine their lists into a master list and pass it on as a reference for future observations. All of the information collected can be combined, using digital cameras or a scanner, and computer software, to create a school or townwide electronic field guide. This data can be submitted and included in a statewide database. For more information about Biodiversity Days in Massachusetts, visit http://www.maccweb.org/biodiversity_days.html.

Assessment Strategies

- Clearly state your expectations for the students’ work. Outline the expectations for how field guide data should be organized and recorded. It is helpful to have a sample of the level of work expected, such as a high quality field guide developed by previous students.
- Develop a rubric that assesses how accurately the student identifies, classifies, catalogs, and places the organisms in a food web.
- As a culminating activity, invite parents and friends to school and ask students to present their findings. The teacher may wish to ask a community member to help evaluate the students’ presentations.

Life Science Learning Standards

Grades 3–5

1. Classify plants and animals according to the physical characteristics that they share.
3. Recognize that plants and animals go through predictable life cycles that include birth, growth, development, reproduction, and death.

Life Science (Biology), Grades 6–8

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES
Classification of Organisms	
1. Classify organisms into the currently recognized kingdoms according to characteristics that they share. Be familiar with organisms from each kingdom.	
Structure and Function of Cells	
2. Recognize that all organisms are composed of cells, and that many organisms are single-celled (unicellular), e.g., bacteria, yeast. In these single-celled organisms, one cell must carry out all of the basic functions of life.	Observe, describe, record, and compare a variety of unicellular organisms found in aquatic ecosystems.
3. Compare and contrast plant and animal cells, including major organelles (cell membrane, cell wall, nucleus, cytoplasm, chloroplasts, mitochondria, vacuoles).	Observe a range of plant and animal cells to identify the cell wall, cell membrane, chloroplasts, vacuoles, nucleus, and cytoplasm when present.
4. Recognize that within cells, many of the basic functions of organisms (e.g., extracting energy from food and getting rid of waste) are carried out. The way in which cells function is similar in all living organisms.	
Systems in Living Things	
5. Describe the hierarchical organization of multicellular organisms from cells to tissues to organs to systems to organisms.	
6. Identify the general functions of the major systems of the human body (digestion, respiration, reproduction, circulation, excretion, protection from disease, and movement, control, and coordination) and describe ways that these systems interact with each other.	

Life Science (Biology), Grades 6–8

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES
Reproduction and Heredity	
7. Recognize that every organism requires a set of instructions that specifies its traits. These instructions are stored in the organism’s chromosomes. Heredity is the passage of these instructions from one generation to another.	
8. Recognize that hereditary information is contained in genes located in the chromosomes of each cell. A human cell contains about 30,000 different genes on 23 different chromosomes.	
9. Compare sexual reproduction (offspring inherit half of their genes from each parent) with asexual reproduction (offspring is an identical copy of the parent’s cell).	
Evolution and Biodiversity	
10. Give examples of ways in which genetic variation and environmental factors are causes of evolution and the diversity of organisms.	
11. Recognize that evidence drawn from geology, fossils, and comparative anatomy provides the basis of the theory of evolution.	Is the pterodactyl a flying reptile or the ancestor of birds? Discuss both possibilities based on the structural characteristics shown in pterodactyl fossils and those of modern birds and reptiles.
12. Relate the extinction of species to a mismatch of adaptation and the environment.	Relate how numerous species could not adapt to habitat destruction and overkilling by humans, e.g., woolly mammoth, passenger pigeon, great auk.
Living Things and Their Environment	
13. Give examples of ways in which organisms interact and have different functions within an ecosystem that enable the ecosystem to survive.	Study several symbiotic relationships such as oxpecker (bird) with rhinoceros (mammal). Identify specific benefits received by one or both partners.

Life Science (Biology), Grades 6–8

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES
Energy and Living Things	
14. Explain the roles and relationships among producers, consumers, and decomposers in the process of energy transfer in a food web.	Distribute pictures of various producers, consumers, and decomposers to groups of students. Have each group organize the pictures according to the relationships among the pictured species and write a paragraph that explains the roles and relationships.
15. Explain how dead plants and animals are broken down by other living organisms and how this process contributes to the system as a whole.	Observe decomposer organisms in a compost heap on the school grounds, a compost column in a plastic bottle, or a worm bin. Use compost for starting seeds in the classroom or in a schoolyard garden.
16. Recognize that producers (plants that contain chlorophyll) use the energy from sunlight to make sugars from carbon dioxide and water through a process called photosynthesis. This food can be used immediately, stored for later use, or used by other organisms.	Test for sugars and starch in plant leaves.
Changes in Ecosystems Over Time	
17. Identify ways in which ecosystems have changed throughout geologic time in response to physical conditions, interactions among organisms, and the actions of humans. Describe how changes may be catastrophes such as volcanic eruptions or ice storms.	Study changes in an area of the schoolyard or a local ecosystem over an extended period. Students might even compare their observations to those made by students in previous years.
18. Recognize that biological evolution accounts for the diversity of species developed through gradual processes over many generations.	

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 (Archaea, Bacteria, 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.

Biology, High School

Learning Standards for a Full First-Year Course

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.

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

Physical Sciences *(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 **grades PreK–2**, students’ curiosity is engaged when they observe physical processes and sort objects by different criteria. During these activities, students learn basic concepts about how things are alike or different. As they push, pull, and transform objects by acting upon them, the students see the results of their actions and begin to understand how part of their world works. They continue to build understanding by telling stories about what they did and what they found out.

Learning standards for PreK–2 fall under the following three subtopics: *Observable Properties of Objects*; *States of Matter*; and *Position and Motion of Objects*.

- In **grades 3–5**, students’ growth in their understanding of ordinary things allows them to make the intellectual connections necessary to understand how the physical world works. Students are able to design simple comparative tests, carry out the tests, collect and record data, analyze results, and communicate their findings to others.

Learning standards for grades 3–5 fall under the following three subtopics: *Properties of Objects and Materials*; *States of Matter*; and *Forms of Energy* (including electrical, magnetic, sound, and light).

- In **grades 6–8**, students still need concrete, physical-world experiences to help them develop concepts associated with motion, mass, volume, and energy. As they learn to make accurate measurements using a variety of instruments, their experiments become more quantitative and their physical models more precise. Students in these grades are able to graph one measurement in relation to another, such as temperature change over time. They may collect data by using microcomputer- or calculator-based laboratories (MBL or CBL), and can learn to make sense immediately of graphical and other abstract representations essential to scientific understanding.

Learning standards for grades 6–8 fall under the following five subtopics: *Properties of Matter; Elements, Compounds, and Mixtures; Motion of Objects; Forms of Energy; and Heat Energy.*

- 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.

Physical Sciences (Chemistry and Physics), Grades PreK–2

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES	SUGGESTED EXTENSIONS TO LEARNING IN TECHNOLOGY/ENGINEERING (Technology/Engineering standards for grades PreK–2 are on page 85.)
Observable Properties of Objects		
1. Sort objects by observable properties such as size, shape, color, weight, and texture.	Manipulate, observe, compare, describe, and group objects found in the classroom, on the playground, and at home.	<i>Predict from looking at the shape of a simple tool or object what actions it might be used for (e.g., pliers, letter opener, paperweight). (T/E 1.2, 2.1)</i>
States of Matter		
2. Identify objects and materials as solid, liquid, or gas. Recognize that solids have a definite shape and that liquids and gases take the shape of their container.	Using transparent containers of very different shapes (e.g., cylinder, cone, cube) pour water from one container into another. Observe and discuss the “changing shape” of the water.	<i>Ask students to bring in different types of containers from home. Discuss and demonstrate whether the containers are appropriate to hold solids and liquids (e.g., an unwaxed cardboard box will absorb water and eventually disintegrate while a glass bottle will not). (T/E 1.1, 1.2)</i>
Position and Motion of Objects		
3. Describe the various ways that objects can move, such as in a straight line, zigzag, back-and-forth, round-and-round, fast, and slow.	Use a spinning toy (e.g., a top) to explore round-and-round motion and a rocking toy (e.g., a rocking horse) to explore back-and-forth motion.	<i>Using construction paper and glue, design a three-dimensional object that will roll in a straight line and a three-dimensional object that will roll around in a circle. (T/E 1.3, 2.1)</i>
4. Demonstrate that the way to change the motion of an object is to apply a force (give it a push or a pull). The greater the force, the greater the change in the motion of the object.	Push and pull objects on a hard, smooth surface. Make predictions as to what directions they will move and how far they will go. Repeat using various surfaces (e.g., rough, soft).	
5. Recognize that under some conditions, objects can be balanced.	Try to make a long thin rectangular block of wood stand upright on each face. Note that it stands (balances) very easily on some faces, but not on all.	<i>Design a lever, putting unequal weights on the ends of the balance board. Observe. Now find ways to restore the balance by moving the fulcrum, keeping each weight in the same place. Discuss what happens. (T/E 2.1)</i>

Physical Sciences (Chemistry and Physics), Grades 3–5

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES	SUGGESTED EXTENSIONS TO LEARNING IN TECHNOLOGY/ENGINEERING <small>(Technology/Engineering standards for grades 3–5 are on page 86.)</small>
Properties of Objects and Materials		
1. Differentiate between properties of objects (e.g., size, shape, weight) and properties of materials (e.g., color, texture, hardness).	Gather a variety of solid objects. Collect data on properties of these objects, such as origin (human-made or natural), weight (heavy, medium, light), length, odor, color, hardness, and flexibility.	<i>Given a variety of objects made of different materials, ask questions and make predictions about the hardness, flexibility, and strength of each. Test to see if the predictions were correct. (T/E 1.1)</i>
States of Matter		
2. Compare and contrast solids, liquids, and gases based on the basic properties of each of these states of matter.	Design several stations, each of which demonstrates a state of matter (e.g., water table, balloon and fan table, sand and block table).	<i>Design one container for each state of matter, taking into account which material properties are important (e.g., size, shape, flexibility). (T/E 1.1, 2.3)</i>
3. Describe how water can be changed from one state to another by adding or taking away heat.	Do simple investigations to observe evaporation, condensation, freezing, and melting. Confirm that water expands upon freezing.	<i>Using given insulating materials, try to keep an ice cube from melting. (T/E 1.1)</i>
Forms of Energy		
4. Identify the basic forms of energy (light, sound, heat, electrical, and magnetic). Recognize that energy is the ability to cause motion or create change.	Play music through a speaker with and without a grill cover. Discuss the differences in sound.	<i>Design and construct a candle wheel that demonstrates how heat can cause a propeller to spin. (T/E 1.1, 1.2, 2.2, 2.3)</i>
5. Give examples of how energy can be transferred from one form to another.	Rub two pieces of wood together (mechanical energy) and observe the change in temperature of the wood.	<i>Design and build a simple roller coaster for a marble or toy car to demonstrate how energy changes from one form to another. (T/E 2.2, 2.3)</i>

Physical Sciences (Chemistry and Physics), Grades 3–5

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES	SUGGESTED EXTENSIONS TO LEARNING IN TECHNOLOGY/ENGINEERING <small>(Technology/Engineering standards for grades 3–5 are on page 86.)</small>
Electrical Energy		
6. Recognize that electricity in circuits requires a complete loop through which an electrical current can pass, and that electricity can produce light, heat, and sound.		<ul style="list-style-type: none"> • Using graphic symbols, draw and label a simple electric circuit. (T/E 2.2) • Using batteries, bulbs, and wires, build a series circuit. (T/E 1.2, 2.2)
7. Identify and classify objects and materials that conduct electricity and objects and materials that are insulators of electricity.	Provide a collection of materials that are good conductors and good insulators. Have students determine each material's electrical conductivity by testing the material with a simple battery/bulb circuit.	<i>Select from a variety of materials (e.g., cloth, cardboard, Styrofoam, plastic) to design and construct a simple device (prototype) that could be used as an insulator. Do a simple test of its effectiveness. (T/E 1.1, 1.2, 2.2, 2.3)</i>
8. Explain how electromagnets can be made, and give examples of how they can be used.		<i>Make an electromagnet with a six-volt battery, insulated wire, and a large nail. (T/E 1.2, 2.1, 2.2, 2.3)</i>
Magnetic Energy		
9. Recognize that magnets have poles that repel and attract each other.	Balance ring magnets on a pencil. Note: The shape of a ring magnet obscures the locations of its poles.	<i>Design and build a magnetic device to sort steel from aluminum materials for recycling. (T/E 1.1)</i>
10. Identify and classify objects and materials that a magnet will attract and objects and materials that a magnet will not attract.	Test a variety of materials with assorted magnets. Include samples of pure iron, magnetic steel, and non-magnetic metals in the materials tested. Mention the two other magnetic metals: pure cobalt and pure nickel. Test a U.S. five-cent coin to answer the question "Is a U.S. nickel coin made of pure nickel?"	

Physical Sciences (Chemistry and Physics), Grades 3–5

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES	SUGGESTED EXTENSIONS TO LEARNING IN TECHNOLOGY/ENGINEERING <small>(Technology/Engineering standards for grades 3–5 are on page 86.)</small>
Sound Energy		
11. Recognize that sound is produced by vibrating objects and requires a medium through which to travel. Relate the rate of vibration to the pitch of the sound.	Use tuning forks to demonstrate the relationship between vibration and sound.	<i>Design and construct a simple telephone (prototype) using a variety of materials (e.g., paper cups, string, tin cans, wire). Determine which prototype works best and why. (T/E 1.1, 1.2, 2.2, 2.3)</i>
Light Energy		
12. Recognize that light travels in a straight line until it strikes an object or travels from one medium to another, and that light can be reflected, refracted, and absorbed.	Use a flashlight, mirrors, and water to demonstrate reflection and refraction.	<i>Design and build a prototype to inhibit solar heating of a car (e.g., windshield reflector, window tinting). (T/E 1.2, 2.1, 2.3)</i>

Physical Sciences (Chemistry and Physics), Grades 6–8

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES
Properties of Matter	
1. Differentiate between weight and mass, recognizing that weight is the amount of gravitational pull on an object.	Determine the weight of a dense object in air and in water. Explain how the results are related to the different definitions of mass and weight.
2. Differentiate between volume and mass. Define density.	
3. Recognize that the measurement of volume and mass requires understanding of the sensitivity of measurement tools (e.g., rulers, graduated cylinders, balances) and knowledge and appropriate use of significant digits.	Calculate the volumes of regular objects from linear measurements. Measure the volumes of the same objects by displacement of water. Use the metric system. Discuss the accuracy limits of these procedures and how these limits explain any observed differences between the calculated volumes and the measured volumes.
4. Explain and give examples of how mass is conserved in a closed system.	Melt, dissolve, and precipitate various substances to observe examples of the conservation of mass.
Elements, Compounds, and Mixtures	
5. Recognize that there are more than 100 elements that combine in a multitude of ways to produce compounds that make up all of the living and nonliving things that we encounter.	Demonstrate with atomic models (e.g., ball and stick) how atoms can combine in a large number of ways. Explain why the number of combinations is large, but still limited. Also use the models to demonstrate the conservation of mass in the modeled chemical reactions.
6. Differentiate between an atom (the smallest unit of an element that maintains the characteristics of that element) and a molecule (the smallest unit of a compound that maintains the characteristics of that compound).	Use atomic models (or Lego blocks, assigning colors to various atoms) to build molecules of water, sodium chloride, carbon dioxide, ammonia, etc.
7. Give basic examples of elements and compounds.	Heat sugar in a crucible with an inverted funnel over it. Observe carbon residue and water vapor in the funnel as evidence of the breakdown of components. Continue heating the carbon residue to show that carbon residue does not decompose. Safety note: sugar melts at a very high temperature and can cause serious burns.
8. Differentiate between mixtures and pure substances.	

Physical Sciences (Chemistry and Physics), Grades 6–8

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES
Elements, Compounds, and Mixtures (cont.)	
9. Recognize that a substance (element or compound) has a melting point and a boiling point, both of which are independent of the amount of the sample.	
10. Differentiate between physical changes and chemical changes.	Demonstrate with molecular ball-and-stick models the physical change that converts liquid water into ice. Also demonstrate with molecular ball-and-stick models the chemical change that converts hydrogen peroxide into water and oxygen gas.
Motion of Objects	
11. Explain and give examples of how the motion of an object can be described by its position, direction of motion, and speed.	
12. Graph and interpret distance vs. time graphs for constant speed.	
Forms of Energy	
13. Differentiate between potential and kinetic energy. Identify situations where kinetic energy is transformed into potential energy and vice versa.	
Heat Energy	
14. Recognize that heat is a form of energy and that temperature change results from adding or taking away heat from a system.	
15. Explain the effect of heat on particle motion through a description of what happens to particles during a change in phase.	
16. Give examples of how heat moves in predictable ways, moving from warmer objects to cooler ones until they reach equilibrium.	Place a thermometer in a ball of clay and place this in an insulated cup filled with hot water. Record the temperature every minute. Then remove the thermometer and ball of clay and place them in an insulated cup of cold water that contains a second thermometer. Observe and record the changes in temperature on both thermometers. Explain the observations in terms of heat flow, including direction of heat flow and why it stops.

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).

Chemistry, High School

Learning Standards for a Full First-Year Course

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).

Chemistry, High School

Learning Standards for a Full First-Year Course

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.

Chemistry, High School

Learning Standards for a Full First-Year Course

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.

Chemistry, High School

Learning Standards for a Full First-Year Course

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.

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.

Introductory Physics, High School

Learning Standards for a Full First-Year Course

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.

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- 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.

Introductory Physics, High School

Learning Standards for a Full First-Year Course

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.

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- ✓ 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.

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- ✓ 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

WHAT IT LOOKS LIKE IN THE CLASSROOM

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.

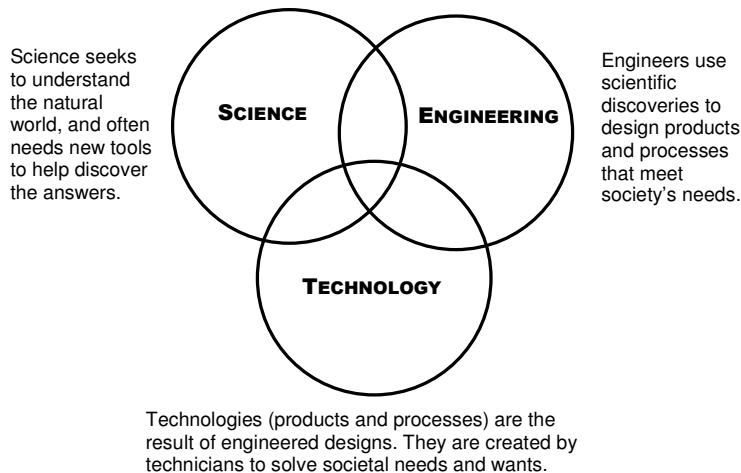
- Explain diagrams and charts that represent relationships of variables.

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.

- Even before entering **grades PreK–2**, students are experienced technology users. Their natural curiosity about how things work is clear to any adult who has ever watched a child doggedly work to improve the design of a paper airplane, or to take apart a toy to explore its insides. They are also natural engineers and inventors, builders of sandcastles at the beach and forts under furniture. Most students in grades PreK–2 are fascinated with technology. While learning the safe uses of tools and materials that underlie engineering solutions, PreK–2 students are encouraged to manipulate materials that enhance their three-dimensional visualization skills—an essential component of the ability to design. They identify and describe characteristics of natural and humanmade materials and their possible uses, and identify uses of basic tools and materials (e.g., glue, scissors, tape, ruler, paper, toothpicks, straws, spools). In addition, PreK–2 students learn to identify tools and simple machines used for specific purposes (e.g., ramp, wheel, pulley, lever). They also learn to describe how human beings use parts of the body as tools.

Learning standards for PreK–2 fall under the following two subtopics: *Materials and Tools*; and *Engineering Design*.

- Students in **grades 3–5** learn how appropriate materials, tools, and machines extend our ability to solve problems and invent. They identify materials used to accomplish a design task based on the materials' specific properties, and explain which materials and tools are appropriate to construct a given prototype. They achieve a higher level of engineering design skill by recognizing a need or problem, learning different ways that the problem can be represented, and working with a variety of materials and tools to create a product or system to address the problem.

Learning standards for grades 3–5 fall under the following two subtopics: *Materials and Tools*; and *Engineering Design*.

- In **grades 6–8**, students pursue engineering questions and technological solutions that emphasize research and problem solving. They identify and understand the five elements of a technology system (goal, inputs, processes, outputs, and feedback). They acquire basic safety skills in the use of hand tools, power tools, and machines. They explore engineering design; materials, tools, and machines; and communication, manufacturing, construction, transportation, and bioengineering technologies. Starting in grades 6–8 and extending through grade 10, the topics of power and energy are incorporated into the study of most areas of technology. Grades 6–8 students use knowledge acquired in their mathematics and science curricula to understand engineering. They achieve a more advanced level of skill in engineering design by learning to conceptualize a problem, design prototypes in three dimensions, and use hand and power tools to construct their prototypes, test their prototypes, and make modifications as necessary. The culmination of the engineering design experience is the development and delivery of an engineering presentation. Because of the hands-on, active nature of the technology/engineering environment, it is strongly recommended that it be taught by teachers who are certified in technology education, and who are very familiar with the safe use of tools and machines.

Learning standards for grades 6–8 fall under the following seven subtopics: *Materials, Tools, and Machines; Engineering Design; Communication Technologies; Manufacturing Technologies; Construction Technologies; Transportation Technologies; and Bioengineering Technologies.*

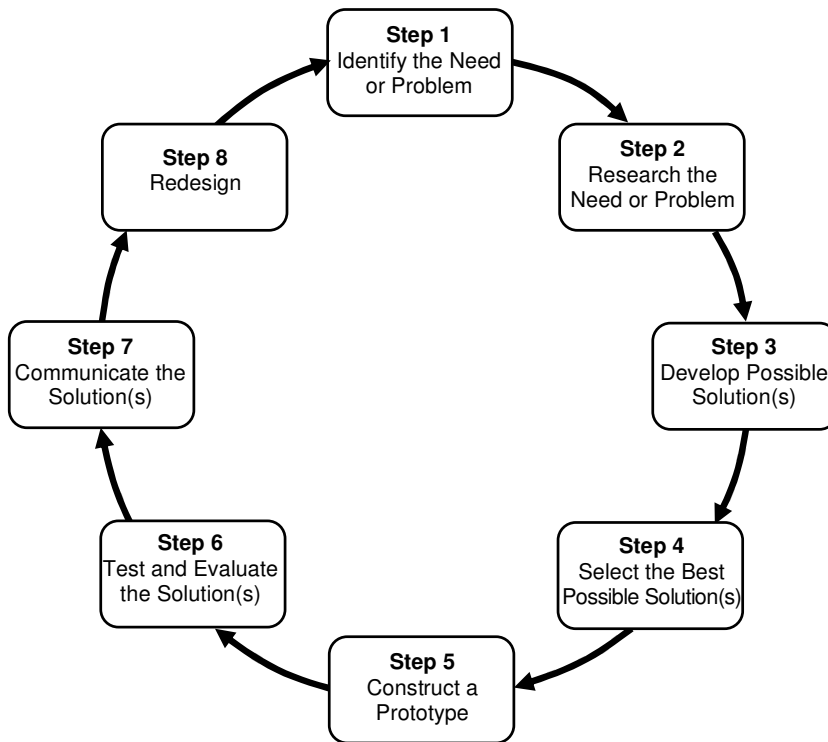
- In **high school**, students develop their ability to solve problems in technology/engineering using mathematical and scientific concepts. High school students are able to relate concepts and principles they have learned in science with knowledge gained in the study of technology/engineering. For example, 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, Grades PreK–2

Please note: Suggested extensions to learning in technology/engineering for grades PreK–2 are listed with the science learning standards. See pages 25 (Earth and Space Science), 44–45 (Life Science), and 63 (Physical Sciences).

LEARNING STANDARDS

1. Materials and Tools

Central Concept: Materials both natural and human-made have specific characteristics that determine how they will be used.

- 1.1 Identify and describe characteristics of natural materials (e.g., wood, cotton, fur, wool) and human-made materials (e.g., plastic, Styrofoam).
- 1.2 Identify and explain some possible uses for natural materials (e.g., wood, cotton, fur, wool) and human-made materials (e.g., plastic, Styrofoam).
- 1.3 Identify and describe the safe and proper use of tools and materials (e.g., glue, scissors, tape, ruler, paper, toothpicks, straws, spools) to construct simple structures.

2. Engineering Design

Central Concept: Engineering design requires creative thinking and consideration of a variety of ideas to solve practical problems.

- 2.1 Identify tools and simple machines used for a specific purpose, e.g., ramp, wheel, pulley, lever.
- 2.2 Describe how human beings use parts of the body as tools (e.g., teeth for cutting, hands for grasping and catching), and compare their use with the ways in which animals use those parts of their bodies.

Technology/Engineering, Grades 3–5

Please note: Suggested extensions to learning in technology/engineering for grades 3–5 are listed with the science learning standards. See pages 26–29 (Earth and Space Science), 46–49 (Life Science), and 64–66 (Physical Sciences).

LEARNING STANDARDS

1. Materials and Tools

Central Concept: Appropriate materials, tools, and machines extend our ability to solve problems and invent.

- 1.1 Identify materials used to accomplish a design task based on a specific property, e.g., strength, hardness, and flexibility.
- 1.2 Identify and explain the appropriate materials and tools (e.g., hammer, screwdriver, pliers, tape measure, screws, nails, and other mechanical fasteners) to construct a given prototype safely.
- 1.3 Identify and explain the difference between simple and complex machines, e.g., hand can opener that includes multiple gears, wheel, wedge, gear, and lever.

2. Engineering Design

Central Concept: Engineering design requires creative thinking and strategies to solve practical problems generated by needs and wants.

- 2.1 Identify a problem that reflects the need for shelter, storage, or convenience.
- 2.2 Describe different ways in which a problem can be represented, e.g., sketches, diagrams, graphic organizers, and lists.
- 2.3 Identify relevant design features (e.g., size, shape, weight) for building a prototype of a solution to a given problem.
- 2.4 Compare natural systems with mechanical systems that are designed to serve similar purposes, e.g., a bird's wings as compared to an airplane's wings.

Technology/Engineering, Grades 6–8

Please note: The number(s) in parentheses following each suggested learning activity refer to the related grades 6–8 Technology/Engineering learning standard(s).

LEARNING STANDARDS	SUGGESTED LEARNING ACTIVITIES
<p>1. Materials, Tools, and Machines <i>Central Concept:</i> Appropriate materials, tools, and machines enable us to solve problems, invent, and construct.</p>	
<p>1.1 Given a design task, identify appropriate materials (e.g., wood, paper, plastic, aggregates, ceramics, metals, solvents, adhesives) based on specific properties and characteristics (e.g., strength, hardness, and flexibility).</p> <p>1.2 Identify and explain appropriate measuring tools, hand tools, and power tools used to hold, lift, carry, fasten, and separate, and explain their safe and proper use.</p> <p>1.3 Identify and explain the safe and proper use of measuring tools, hand tools, and machines (e.g., band saw, drill press, sander, hammer, screwdriver, pliers, tape measure, screws, nails, and other mechanical fasteners) needed to construct a prototype of an engineering design.</p>	<ul style="list-style-type: none"> • Conduct tests for strength, hardness, and flexibility of various materials (e.g., wood, paper, plastic, ceramics, metals). (1.1) • Design and build a catapult that will toss a marshmallow. (1.1, 1.2, 1.3) • Use a variety of hand tools and machines to change materials into new forms through the external processes of forming, separating, and combining, and through processes that cause internal change(s) to occur. (1.2)
<p>2. Engineering Design <i>Central Concept:</i> Engineering design is an iterative process that involves modeling and optimizing to develop technological solutions to problems within given constraints.</p>	
<p>2.1 Identify and explain the steps of the engineering design process, i.e., identify the need or problem, research the problem, develop possible solutions, select the best possible solution(s), construct a prototype, test and evaluate, communicate the solution(s), and redesign.</p> <p>2.2 Demonstrate methods of representing solutions to a design problem, e.g., sketches, orthographic projections, multiview drawings.</p> <p>2.3 Describe and explain the purpose of a given prototype.</p> <p>2.4 Identify appropriate materials, tools, and machines needed to construct a prototype of a given engineering design.</p> <p>2.5 Explain how such design features as size, shape, weight, function, and cost limitations would affect the construction of a given prototype.</p> <p>2.6 Identify the five elements of a universal systems model: goal, inputs, processes, outputs, and feedback.</p>	<ul style="list-style-type: none"> • Given a prototype, design a test to evaluate whether it meets the design specifications. (2.1) • Using test results, modify the prototype to optimize the solution (i.e., bring the design closer to meeting the design constraints). (2.1) • Communicate the results of an engineering design through a coherent written, oral, or visual presentation. (2.1) • Develop plans, including drawings with measurements and details of construction, and construct a model of the solution to a problem, exhibiting a degree of craftsmanship. (2.2)

Technology/Engineering, Grades 6–8

LEARNING STANDARDS	SUGGESTED LEARNING ACTIVITIES
3. Communication Technologies <i>Central Concept:</i> Ideas can be communicated through engineering drawings, written reports, and pictures.	
3.1 Identify and explain the components of a communication system, i.e., source, encoder, transmitter, receiver, decoder, storage, retrieval, and destination.	
3.2 Identify and explain the appropriate tools, machines, and electronic devices (e.g., drawing tools, computer-aided design, and cameras) used to produce and/or reproduce design solutions (e.g., engineering drawings, prototypes, and reports).	
3.3 Identify and compare communication technologies and systems, i.e., audio, visual, printed, and mass communication.	
3.4 Identify and explain how symbols and icons (e.g., international symbols and graphics) are used to communicate a message.	
4. Manufacturing Technologies <i>Central Concept:</i> Manufacturing is the process of converting raw materials (primary process) into physical goods (secondary process), involving multiple industrial processes (e.g., assembly, multiple stages of production, quality control).	
4.1 Describe and explain the manufacturing systems of custom and mass production.	
4.2 Explain and give examples of the impacts of interchangeable parts, components of mass-produced products, and the use of automation, e.g., robotics.	
4.3 Describe a manufacturing organization, e.g., corporate structure, research and development, production, marketing, quality control, distribution.	
4.4 Explain basic processes in manufacturing systems, e.g., cutting, shaping, assembling, joining, finishing, quality control, and safety.	
5. Construction Technologies <i>Central Concept:</i> Construction technology involves building structures in order to contain, shelter, manufacture, transport, communicate, and provide recreation.	
5.1 Describe and explain parts of a structure, e.g., foundation, flooring, decking, wall, roofing systems.	Design and construct a bridge following specified design criteria (e.g., size, materials used). Test the design for durability and structural stability. (5.3)
5.2 Identify and describe three major types of bridges (e.g., arch, beam, and suspension) and their appropriate uses (e.g., site, span, resources, and load).	

Technology/Engineering, Grades 6–8

LEARNING STANDARDS	SUGGESTED LEARNING ACTIVITIES
5. Construction Technologies (cont.)	
5.3 Explain how the forces of tension, compression, torsion, bending, and shear affect the performance of bridges.	
5.4 Describe and explain the effects of loads and structural shapes on bridges.	
6. Transportation Technologies <i>Central Concept:</i> Transportation technologies are systems and devices that move goods and people from one place to another across or through land, air, water, or space.	
6.1 Identify and compare examples of transportation systems and devices that operate on or in each of the following: land, air, water, and space.	<ul style="list-style-type: none"> • Design a model vehicle (with a safety belt restraint system and crush zones to absorb impact) to carry a raw egg as a passenger. (6.1) • Design and construct a magnetic levitation vehicle (e.g., as used in the monorail system). Discuss the vehicle's benefits and trade-offs. (6.2) • Conduct a group discussion of the major technologies in transportation. Divide the class into small groups and discuss how the major technologies might affect future design of a transportation mode. After the group discussions, ask the students to draw a design of a future transportation mode (car, bus, train, plane, etc.). Have the students present their vehicle designs to the class, including discussion of the subsystems used. (6.1, 6.3)
6.2 Given a transportation problem, explain a possible solution using the universal systems model.	
6.3 Identify and describe three subsystems of a transportation vehicle or device, i.e., structural, propulsion, guidance, suspension, control, and support.	
6.4 Identify and explain lift, drag, friction, thrust, and gravity in a vehicle or device, e.g., cars, boats, airplanes, rockets.	
7. Bioengineering Technologies <i>Central Concept:</i> Bioengineering technologies explore the production of mechanical devices, products, biological substances, and organisms to improve health and/or contribute improvements to our daily lives.	
7.1 Explain examples of adaptive or assistive devices, e.g., prosthetic devices, wheelchairs, eyeglasses, grab bars, hearing aids, lifts, braces.	Brainstorm and evaluate alternative ideas for an adaptive device that will make life easier for a person with a disability, such as a device that picks up objects from the floor. (7.1)
7.2 Describe and explain adaptive and assistive bioengineered products, e.g., food, bio-fuels, irradiation, integrated pest management.	

WHAT IT LOOKS LIKE IN THE CLASSROOM

Local Wonders

Adapted from the *Building Big Activity Guide*, pp. 36–37 (www.pbs.org/wgbh/buildingbig)

Technology/Engineering, Grades 6–8

After building newspaper towers and talking about structures and foundations, sixth-graders at the Watertown, Massachusetts Boys and Girls Club brainstormed a list of interesting structures in their town. They selected St. Patrick’s, an elaborate church across the street from the clubhouse, as the focus for an investigation about a “Local Wonder.”

The students began their investigation by brainstorming questions about their Local Wonder. Questions that focused on engineering included the following:

- When was it built?
- What is it made of?
- Why did the builders choose that material?
- What is underneath the building?
- What holds it up?
- What keeps it from falling down?
- How was it built?
- Were there any problems during construction and how were they solved?

Questions with a social/environmental focus included the following:

- Why was it built?
- Who built it?
- What did the area look like before it was built?

Next, the students participated in hands-on activities that explored basic engineering principles such as force, compression, tension, shape, and torsion. They toured the church, took photographs, researched the structure, interviewed long-time community members about their memories about the structure, and interviewed engineers, architects, and contractors who worked on the construction project. They conducted research at the library, the Historical Society, and the Watertown Building Inspector’s office, where they acquired the building’s plans and copies of various permits. They used this information to develop a timeline of the building’s history.

Students used the following method to estimate the size of the church: First, they selected one student, Josh, and measured his height. Then Josh stood next to the church, while the rest of the club members stood across the street. The teacher asked each student to close one eye and use his or her fingers to “stack” Josh’s height up to the top of the church. The each student multiplied the number of times he or she stacked Josh’s height, to find the total estimated height of the church.

Small groups of students met and prepared final reports, using the following generic outline:

- I Name of group submitting report
- II Name and description of structure (identify the type of structure, such as a bridge or skyscraper, and describe and explain its parts)
- III Location of structure
- IV Approximate date structure was completed
- V Approximate size of structure
- VI Why we chose this particular Local Wonder
- VII What’s important about our Local Wonder

WHAT IT LOOKS LIKE IN THE CLASSROOM

- VIII Things we learned about our Local Wonder (include information such as type of construction, engineering design concepts, and forces acting on the structure)
- IX Interesting facts about our Local Wonder

Your community may not have an Eiffel Tower or a Hoover Dam, but for your Local Wonder you can choose any structure in your community that is significant because of its appearance, uniqueness, or historical or social impact. Consider local bridges, tunnels, skyscrapers or other buildings, domes, dams, and other constructions. You can e-mail the American Society of Civil Engineers at buildingbig@asce.org to connect with a volunteer civil engineer for this activity. To help select your Local Wonder, have the class brainstorm a list or collect some photographs for discussion.

Any group that completes this project can submit its investigation to pbs.org/buildingbig. Send them your complete report, including photographs or original drawings of your local wonder. Students should be encouraged to draw the structure from a variety of different perspectives. Students can also share their reports with other classes in their school or at a local town meeting.

Assessment Strategies

- Share examples of other previous groups' completed investigations with your students at the beginning of the project. Discuss and develop criteria for effective reports, and identify what constitutes quality work.
- Students can record their learning in an engineering journal. Students can write down each day what they have learned, questions that they may have, resources they found helpful, and resources they need to consult. The teacher should read the journals to monitor students' progress and levels of participation, and to identify what topics the students have mastered and which areas of learning need to be reinforced by additional instruction.
- Post your Local Wonder report on your school district website, on the town website, or on a town agency's website (e.g., the Chamber of Commerce). Include an e-mail address and encourage feedback.
- At the end of the unit, provide the students with a photograph of a similar structure from another town or area. Ask them to write a final paper that compares this structure to their own Local Wonder. How are they alike? Different? Compare the materials, designs, and purposes of these structures.

Engineering Design Learning Standards

Grades 6–8

- 2.2 Demonstrate methods of representing solutions to a design problem (e.g., sketches, orthographic projections, multi-view drawings).
- 2.5 Explain how such design features as size, shape, weight, function, and cost limitations would affect the construction of a given prototype.

Construction Technologies Learning Standards (Applicable standards may depend on structure selected.)

Grades 6–8

- 5.1 Describe and explain parts of a structure (e.g., foundation, flooring, decking, wall, roofing systems).
- 5.2 Identify and describe three major types of bridges (i.e., arch, beam, and suspension) and their appropriate uses (e.g., based on site, span, resources, and load).
- 5.3 Explain how the forces of tension, compression, torsion, bending, and shear affect the performance of bridges.
- 5.4 Describe and explain the effects of load and structural shape on bridges.

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., $\frac{1}{4}'' = 1'0''$, $1 \text{ cm} = 1 \text{ m}$).
- 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).

Technology/Engineering, High School

Learning Standards for a Full First-Year Course

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., 45° elbow, 90° 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.

Technology/Engineering, High School

Learning Standards for a Full First-Year Course

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)

Technology/Engineering, High School

Learning Standards for a Full First-Year Course

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., $\frac{1}{4}'' = 1'0''$, $1 \text{ cm} = 1 \text{ m}$).
- 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. 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)

Suggested Learning Activities for High School Technology/Engineering Learning Standards

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)

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)

Appendices

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.

STRAND: EARTH AND SPACE SCIENCE

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

<p style="text-align: center;">Structure of the Earth</p>		<p>12. Earth’s surface changes due to slow processes such as erosion and weathering, and rapid processes such as landslides, volcanic eruptions, and earthquakes.</p>	<p>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.</p>	<p>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 to reveal Earth’s interior structure and earthquake epicenters. 3.12 The Richter scale and the relative damage incurred by earthquakes.</p>
<p style="text-align: center;">Earth in the Solar System</p>	<p>5. Events around us have repeating patterns, including the seasons of the year, day, and night.</p>	<p>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.</p>	<p>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.</p>	<p>4.2 Influence of gravity and inertia on the rotation and revolution of orbiting bodies; Sun-Earth-moon relationships.</p>
<p style="text-align: center;">Origin and Evolution of Earth</p>			<p>12. The universe contains many billions of galaxies and each galaxy contains many billions of stars.</p>	<p>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.</p>

STRAND: LIFE SCIENCE (BIOLOGY)

Broad Topic		Content of Each Learning Standard			
PK-8	HS	PreK-2	Grades 3-5	Grades 6-8	High School
Characteristics of Living Things	Characteristics of Living Things	<ol style="list-style-type: none"> Animals and plants are living things that grow, reproduce, & need food, air, & water. Characteristics of living and nonliving things. Plants and animals have life cycles that vary. 	<ol style="list-style-type: none"> Physical characteristics of plants and animals Plants and animals go through predictable life cycles, including birth, growth, development, reproduction, and death. Major life cycle stages of the frog and butterfly. 	<ol style="list-style-type: none"> Organisms are classified into kingdoms. 	<ol style="list-style-type: none"> Cellular evidence and modes of nutrition of the six kingdoms.
Structure and Function of Cells	Cell Biology and Biochemistry			<ol style="list-style-type: none"> Organisms are composed of cells, and many organisms are single-celled, where one cell must carry out all basic functions of life. Plant and animal cells have similarities and differences in their major organelles. Basic functions of living organisms are carried out in cells. 	<ol style="list-style-type: none"> Biological organisms are composed primarily of few elements. Molecular structures and functions of the four major categories of organic molecules. Enzymes are catalysts for biochemical reactions affected by a variety of factors. Cell parts/organelles and their functions; cell membranes. Cellular similarities and differences of prokaryotes and eukaryotes. Reactants, products, and purposes of photosynthesis and respiration. Role of ATP in metabolism. The cell cycle and mitosis in asexual reproduction. Meiosis in sexual reproduction. Differences of a virus and a cell.
Systems in Living Things	Anatomy and Physiology	<ol style="list-style-type: none"> Structures in plants that are responsible for food production, support, water transport, reproduction, growth, and protection. 	<ol style="list-style-type: none"> Multicellular organisms can be hierarchically organized from cells to tissues to organs to systems to organisms. General functions of the major systems of the human body, and the interactions of these systems. 	<ol style="list-style-type: none"> The digestive system converts macromolecules into smaller molecules. The circulatory system transports nutrients and oxygen, and removes cell wastes. Kidneys and liver remove waste from blood. The respiratory system provides exchange of O₂ and CO₂. The nervous system mediates communication. The muscular/skeletal system supports the body and allows for movement. Bones produce blood cells. Sexual reproductive system. Communication among cells is required for coordination of body functions. Body systems interact to maintain homeostasis using physiological feedback loops. 	

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

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 exothermic 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.

<p>Acids and Bases and Oxidation-Reduction Reactions</p>				<p>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.</p>
<p>Solutions, Rates of Reaction, and Equilibrium</p>				<p>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.</p>
<p>Reactions and Stoichiometry</p>				<p>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</p>
<p>Chemical Bonding</p>				<p>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 Electronegativity 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.</p>
<p>Periodicity</p>				<p>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.</p>

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

STRAND: TECHNOLOGY/ENGINEERING

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

Manufacturing			<p>4.1 Manufacturing systems of custom and mass production.</p> <p>4.2 Impacts of interchangeable parts, components of mass-produced products, and the use of automation.</p> <p>4.3 Manufacturing organization.</p> <p>4.4 Basic processes in manufacturing systems.</p>	<p>7.1 Manufacturing processes</p> <p>7.2 Criteria necessary to select safe tools and procedures for the manufacturing process.</p> <p>7.3 Advantages of using robotics in the automation of manufacturing processes.</p>
Construction			<p>5.1 Parts of a structure.</p> <p>5.2 Three major types of bridges and their appropriate uses.</p> <p>5.3 The forces of tension, compression, torsion, bending, and shear affect the performance of bridges.</p> <p>5.4 Effects of load and structural shape on bridges.</p>	<p>2.1 Engineering properties of materials used in structures.</p> <p>2.2 Differences between tension, compression, shear, and torsion, and how they relate to the selection of materials in structures.</p> <p>2.3 Bernoulli's principle and its effect on structures.</p> <p>2.4 Resultant force(s) for a combination of live and dead loads.</p> <p>2.6 The purposes of zoning laws and building codes in the design and use of structures.</p>
Transportation			<p>6.1 Transportation systems and devices that operate on or in land, air, water, and space.</p> <p>6.2 Possible solutions to transportation problems, using the universal systems model.</p> <p>6.3 Three subsystems of a transportation vehicle or device.</p> <p>6.4 Lift, drag, friction, thrust, and gravity in a vehicle or device.</p>	
Bio-engineering			<p>7.1 Adaptive and assistive devices.</p> <p>7.2 Adaptive and assistive bioengineered products.</p>	
Fluid Systems				<p>3.1 Differences between open and closed fluid systems.</p> <p>3.2 Hydraulic and pneumatic systems and how each relates to manufacturing and transportation systems.</p> <p>3.3 The ability of a hydraulic system to multiply distance, multiply force, and effect directional change.</p> <p>3.4 The velocity of a liquid moving in a pipe varies inversely with changes in the pipe's cross-sectional area.</p> <p>3.5 Sources of resistance for water moving through a pipe.</p>

Broad Topic	Content of Each Learning Standard			
	PreK–2	Grades 3–5	Grades 6–8	High School
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 II

Additional Learning Activities

for Grade PreK through Grade 8

This appendix presents suggestions for additional activities to enhance the grades PreK through 8 learning standards in Earth and Space Science, Life Science, and Physical Sciences.

Activities printed in regular type are Ideas for Developing Investigations and Learning Experiences. Those in *italics* are *Suggested Extensions to Learning in Technology/Engineering* and, at grades PreK–2 and 3–5, reference the related Technology/Engineering standards. Technology/Engineering standards for grades PreK–2 can be found on page 85; for grades 3–5, they can be found on page 86.

Earth and Space Science

Grades PreK–2, page 25

Standard #1

- Use a hand lens to observe and describe the components and properties of a sample of soil (e.g., color, texture, presence or absence of clumps). Extend the examination to moist topsoil.
- For grades 1–2, conduct the experiment above with thoroughly wet soil and sand. Observe again after all of the samples dry over night.

Standard #2

- *Design and build a simple vehicle system that uses an air-filled, nonlatex balloon as an engine. Distinguish between naturally occurring and human-made materials on the vehicle. (T/E 1.2, 1.3) Safety note: Grades PreK–1 students should **not** be allowed to inflate balloons themselves.*
- *Teacher demonstration: Hold a strip of paper in various positions around a fan to determine patterns in air movement. (T/E 1.1, 1.2)*

Standard #4

- Record the outdoor temperatures in a sunny location and in a shady location. Discuss the reason for the difference in temperatures.
- Grade 2: Conduct the above activity on a sunny day and then repeat on a cloudy day at the same times and locations.

Standard #5

- Observe, record, and discuss seasonal changes as they occur.
- *Design and build a “Rube Goldberg” type of machine that works in a loop, repeating the pattern. (T/E 1.3, 2.1)*

Earth and Space Science (cont.)

Grades 3–5, pages 26–29

Standard #1

- Observe and describe the differences between quartz and mica.
- With a hand lens, examine a sample of coarse sand containing many kinds of grains. Also examine a collection of local rocks. Observe that rocks usually contain grains of many different minerals and that sand grains can be pure minerals (e.g., quartz, mica).
- Show examples of items made from minerals (e.g., jewelry, aluminum foil, cans, glass bottles).
- *Visit a glass factory, or an aluminum or tin production plant. (T/E 1.1, 1.2)*
- *Arrange a visit with experts who work with minerals (e.g., gemologist). (T/E 1.1, 1.2)*
- *Discuss how minerals are used in industry/technology (e.g., diamonds for drilling). (T/E 1.1)*

Standard #2

- Acquire a collection of minerals that includes (a) duplicates of the same mineral that are somewhat different in appearance (size, shape, exact color) and (b) samples of minerals that look similar but are actually different. Sort as accurately as possible. Test all samples using three field tests: magnetism, streak, and hardness. Sort the minerals again if this new information changes prior conclusions about which samples are identical.
- Use a field guide to identify the minerals that you have described above. Compare your list of physical properties with those given in the guide.

Standard #3

- Approximate the role of heat in the formation of metamorphic rocks. Use dry cereal, marshmallows, and chocolate chips to represent three different minerals. Study and record the properties of each “mineral.” Combine and bake. Study properties of the “rocks” and new “minerals” formed by heat. Contrast to preexisting “minerals.”
- Approximate the role of pressure in the formation of metamorphic rocks. Snap wooden toothpicks in half, leaving them connected. Make similar piles of these “mineral grains” side by side on a tray. Place large books on top of one pile and press. Observe differences in the “rocks” brought about by pressure.
- Explain how the toothpick activity can also be used to represent the role of pressure in forming sedimentary rocks. Now the uncompacted toothpicks represent fresh grains of sediment.
- Illustrate the growth of crystals (important in forming both igneous and sedimentary rocks). Make concentrated solutions of various salts. Allow them to evaporate slowly and observe the formation of crystals. Commonly used salts include table salt (sodium chloride), alum, and Epsom salt.
- *Visit a facility that utilizes rocks and minerals in construction materials. (T/E 1.1, 1.2)*

Standard #4

- Engage in composting (worm farms).
- *Construct a mini-landfill. Unearth and observe decomposition of buried waste (e.g., food, paper, plastic, metal). (T/E 2.1, 2.2, 2.3)*

Standard #5

- Prepare different soil mixes using commercial potting soil, worm compost, and sand. Compare growth of plants in the different mixes.
- Fill clear jars half full with soil samples, then fill with water, shake, let settle, and observe the layers.

Standard #7

- Watch national/international weather broadcasts. Discuss the relationships among precipitation, temperature, and location on the globe.

Earth and Space Science (cont.)

Grades 3–5, pages 26–29 (cont.)

Standard #8

- Create weather maps, using basic symbols showing weather patterns, precipitation, etc. Ask students to present their own weather reports to the class.
- Grade 3: Watch local weather reports on television and in the newspaper.
- Grades 4–5: Attempt to forecast the weather for the next day and explain reasons for the forecast.

Standard #10

- Demonstrate in the classroom evaporation, condensation, and precipitation.
- Show on a diagram of the water cycle the effects of regional weather events, such as heavy rainstorms, heavy winter snow totals, and droughts.
- Have students brainstorm and act out the water cycle (see Incredible Journey/Project WET in “Selected Websites for Science and Technology/Engineering Education,” page 153 of this *Framework*).
- Place white flowers (e.g., carnation, rose) in a vase that contains water with food coloring added. Observe the change in flower color and relate observations to the uptake of pollution by plants.
- *Create a simple presentation showing the water cycle. (T/E 2.2)*

Standard #12

- Visit local sites that show examples of the earth changing due to slow processes (e.g., schoolyard, coastline, erosion at Walden Pond) and rapid processes (e.g., localized erosion at Nauset Beach after a large storm). Document the changes using newspaper photographs.
- Visit local sites that show the effects of glacial advance or retreat on the landscape (e.g., drumlins, kettle ponds).
- Observe the effect of winter weathering on roads.
- *Discuss the scales used to measure earth events (e.g., the Richter Scale). (T/E 2.2)*
- *Compare a beaver dam with a human-made dam. What effects on the environment does each have? (T/E 2.4)*

Standard #14

- *Create a model of the solar system and, using a flashlight, demonstrate the effects of Earth’s rotation and revolution. (T/E 2.2, 2.3)*

Standard #15

- Demonstrate the various phases of the moon using a model (light source and sphere).

Grades 6–8, pages 32–33

Standard #1

- Obtain a topographic relief map and a corresponding paper contour map of a coastal area (preferably in Massachusetts). Use both maps to demonstrate the changes in the coastline that would occur if the sea level were to rise by various amounts.
- Use topographic maps to explain an environmental problem, its location, its cause, and a proposed solution.
- Construct a clinometer. If suitable terrain is available, use a clinometer to determine the height of geologic features, the slope of surface features, and the slope of layers of strata. Substitute heights of architectural features and slopes of ramps if necessary.
- From a contour map, build a model that shows the physical features of a selected area and the locations of wildlife/plants.
- Use maps from different time periods to observe changes in landscape.

Earth and Space Science (cont.)

Grades 6–8, pages 32–33 (cont.)

Standard #3

- Using a thermometer, compare levels of heat absorption for white and black cans.
- Investigate heat transfer by placing plastic, metal, and wooden spoons in hot water and determining how quickly they heat up (conduction).
- Investigate heat transfer *from* a room by adding 50 ml of cold water to a cup or beaker. Stir it and record its temperature changes every few minutes over a ten-minute period.
- Investigate heat transfer *to* a room by adding 50 ml of warm water to a cup or beaker. Stir and record temperature changes every few minutes over a ten-minute period.

Standard #6

- Look at maps and photos to observe coastal changes.

Standard #7

- Study the local landscape and, if possible, an unbuilt terrain (e.g., a state park) for signs of glaciation (e.g., eskers, drumlins, kettle holes). Discuss whether any of these features give evidence as to which way the glacier that formed them was moving.

Standard #8

- Explain how a clinometer uses gravity to find the center of the earth, and puts that knowledge to use. Explain how part of this function could be carried out using a spirit level.

Standard #9

- Model solar and lunar eclipses using a dim bulb and two balls.
- If possible, put out tide stakes covered in chalk to observe and measure the height of the tide. Observe changes over time and correlate to the phases of the moon.

Standard #10

- Model day and night using a dim bulb and a ball.
- Use binoculars and telescopes to observe planets and the moon. Estimate the diameter of the largest and smallest craters you observe on the moon. Explain what you measured and how you calculated your answer.
- Observe Mars, Venus, and Jupiter. Compare their observed color and brightness. Did you observe any moons accompanying any of these planets? Explain why or why not.
- Record the location of the moon, Mars, Venus, and Jupiter relative to a nearby bright star. Repeat after about one week and one month. Explain the changes.

Life Science (Biology)

Grades PreK–2, pages 44–45

Standard #1

- Using string, mark out a circle of about two meters in diameter in the schoolyard or a nearby park. Have students survey the biodiversity of the circle. Younger students can look for leaves of different shapes and older students can find out how many different types of plants and animals are found in the circle. Ask how the living things in the circle might be different in different seasons, then test predictions by going out to see.
- *Design and build several cardboard boxes, each of which has a small round opening at a different location on the box. Cover newly germinating seeds with the various boxes and observe how the stems grow toward the light that comes through the openings. (T/E 2.3)*

Life Science (Biology) (cont.)

Grades PreK–2, pages 44–45 (cont.)

Standard #1 (cont.)

- *Build a terrarium containing plants and small animals (e.g., earthworms, other soil organisms, insects). Discuss the needs of living things and let the students participate in maintenance of the terrarium. (T/E 1.1, 1.2, 1.3)*

Standard #2

- Examine a variety of nonliving and living things. Describe differences among them.
- Sort and sub-sort pictures of living things into groups based on characteristics that you can see.

Standard #3

- Observe the changes in physical characteristics during the life cycle of a chick. Note: it is important to provide adequate incubation equipment, space, and housing facilities for the chicks.
- *Compare a bicycle wheel and other cycles in machinery. (T/E 2.2)*

Standard #6

- *Examine and compare human-made objects that are engineered to enhance the senses or to protect parts of bodies that are centers of the senses (e.g., hearing aids, gloves, glasses, ear plugs). (T/E 1.2, 2.2)*

Standard #7

- Discuss animals that hibernate. Some examples from Massachusetts are the garden snail, box turtle, chipmunk, woodchuck, black bear, and bat.
- In the fall, collect samples of the food items (seeds, nuts, grains) that a local chipmunk would store to eat while hibernating. Keep in a dry place over the winter. Notice that these foods do not spoil. Notice that they cannot be found outdoors in the winter. Discuss the high nutritional value of these foods for animals.
- Discuss how animals' fur changes to prepare for winter and compare with what humans do to prepare for winter.
- Compare winter adaptations of wild mammals native to the area (e.g., squirrels, woodchucks, mice, raccoon, deer, bats, coyotes).
- Discuss what happens to leaves that fall in the woods each year (decomposition).
- *Explore objects and technologies used to make human life comfortable during the four seasons and bring examples or pictures of examples from home (e.g., air conditioner, fan, winter coat, wool hat). (T/E 1.1, 2.1)*

Standard #8

- Observe and discuss animals in their natural habitats.
- Observe and record the names of plants and animals in your neighborhood or on a field trip, then prepare a field guide that describes these animals.
- Choose an animal and provide students with a list of its habitat needs. Allow the students to imagine that they are that animal. Can they find what they need to survive (i.e., food, water, shelter/space)?
- *Explain how tools of technology such as glue, scissors, tape, ruler, paper, toothpicks, straws, spools, and other mechanical fasteners can be used to make or build animal habitats. (T/E 1.2, 1.3)*
- *Using pencil and paper or graph paper as tools, sketch a drawing of the front view of an animal habitat made by humans. (T/E 1.3)*

Life Science (Biology) (cont.)

Grades 3–5, pages 46–49

Standard #2

- Observe the cross-sections of various trees. Determine the age of each tree, and relate the variation in distance between the circles of the cross-section to the variation in climate from year to year.
- *Compare the physical properties of hard and soft woods (density, hardness, knots) and relate those properties to the use of each type of wood in construction. (T/E 1.1)*
- *Use magnifying glasses and/or microscopes to observe plant structures. (T/E 1.2)*

Standard #3

- Follow the complete life cycle of a metamorphic organism such as a frog or a moth. Draw pictures of the organism at various stages of development.
- Explore through pictures or videos the life cycle of a nonmetamorphic animal.

Standard #5

- Sort pictures of fish of the same species, noticing which traits vary (e.g., color pattern, size) and which do not (e.g., shape, number of fins).

Standard #6

- Build a human skeleton using found or recycled materials.
- Compare heads, bodies, and tails of different types of fish. Explain how these adaptations help each type of fish survive.

Standard #7

- Discuss the challenges of living in a coastal environment. What are the environmental stresses facing plants and animals, and how do they adapt?

Standard #9

- Observe the ability of a sunflower or tulip to sense light intensity.
- Observe plants' responses to stresses in their environment (e.g., changes in salinity levels or flooding in the salt marsh).

Standard #11

- Compare a coastal food chain to an inland food chain.

Grades 6–8, pages 51–53

Standard #12

- Discuss possible reasons for the extinction of dinosaurs (Sudden change in climate? Drought? Catastrophic geological events?).

Standard #13

- Discuss the dispersal of pollen by bees and other insects and how it enables the reproduction and propagation of plants.
- Investigate the interactions of organisms in a local environment.
- In a wooded area, observe the ecosystem contained in the leaf litter and discuss how it sustains the larger ecosystem of the forest.

Standard #15

- Observe and document the effects of decay on materials (e.g., fruits) left to rot.
- Establish a compost bin. Analyze the decay of the contents and the gradual appearance of various organisms over time.
- Investigate wetland soil. Discuss how organic material is broken down more slowly in anaerobic conditions.

Life Science (Biology) (cont.)

Grades 6–8, pages 51–53 (cont.)

Standard #17

- Research natural and human-caused changes in some of the large-scale ecosystems (biomes) on earth.
- Use computer simulations to model the growth of plants on a plot of land, or a sand dune, or after a volcanic eruption.
- Review the data (on websites) gathered by scientists who are conducting long-term ecological research. How are they monitoring rising sea levels?
- Observe seasonal movement of barrier beaches. Compare jettied and non-jettied beaches.
- Investigate the effects of a tidal restriction on a salt marsh.
- Compare ecosystems with low and high biodiversity (e.g., salt marsh has low biodiversity, rainforest has high biodiversity). Discuss the timeframes in which species have adapted to their environment.

Physical Sciences

Grades PreK–2, page 63

Standard #1

- *Group a variety of objects according to the characteristics that they share (e.g., height, shape, hardness). (T/E 1.1)*
- *Mystery Tactile Box; 20 Questions about the objects in the box. (T/E 1.1)*

Standard #2

- Choose six small transparent closed containers. In each of three, put a different small solid object (e.g., marble, screw, eraser). Partly fill each of the three remaining containers with a different liquid (e.g., water, oil, honey). Close all six containers and shake them. Note that all the solids share a property of definite shape, while liquids do not maintain their shape.
- Observe water as it changes from a solid (ice) to a liquid (water).
- *Using a piece of paper, design a container that can be filled with water. Explore how many times the container can be filled with water before it falls apart. Discuss why some designs may be more effective than others. (T/E 1.1, 1.2)*

Standard #3

- Use solid objects such as a ball, a cube, and a cone. First try to roll each object on a hard smooth level surface. Observe and describe its motion and the path it takes. Next, tilt the surface, place each object on it at the center and release the object. Observe and describe its motion and the path it takes. Repeat using various surfaces (e.g., rough, soft).
- *Design a simple structure that will roll (e.g., cylinder) using simple classroom tools and materials (e.g., construction paper, glue, paste, scissors, tape, straws). Change the design so that the structure will roll in a different direction. (T/E 1.3, 2.1)*

Standard #4

- Measure the distance that objects move on a hard, smooth surface after being pushed or pulled with different force. Repeat using various surfaces (e.g., rough, soft).
- Manipulate various objects. Observe the different methods (forces) that you can use to make objects move. Include pushing with a stick, pulling with a string, and pushing by blowing on a light object.

Physical Sciences (cont.)

Grades PreK–2, page 63 (cont.)

Standard #5

- Balance a large block of wood on a smaller one (fulcrum). Observe that adding some weight to one end of the large block will unbalance it. Find ways to keep it balanced by using two weights, one on each side of the fulcrum.

Grades 3–5, pages 64–66

Standard #1

- Using a variety of objects, identify at least the main material the object is made of (e.g., wood, metal, paper, pottery/ceramic, plastic, glass). Discuss the function of the object and its parts. Discuss how the properties of the material(s) used are suited to the function of the overall object or some part of it.
- *Discuss the different materials that several common objects are made of, and the reasons that those specific materials may have been used. (T/E 1.1)*

Standard #6

- *Design and build a simple game using simple circuits. (T/E 1.2, 2.2)*

Standard #8

- *Design and construct a simple game or toy (prototype) that works because of electromagnets. (T/E 1.1, 1.2, 2.2, 2.3)*

Standard #9

- Provide sealed field detectors (iron filings confined between sheets of plastic or iron filings sealed in oil). Use to show and draw magnetic fields in two and three dimensions.

Standard #12

- *Design and build a periscope from cardboard and mirrors. (T/E 1.1, 1.2, 2.3)*
- *Design and build a pinhole camera. Test the effects of light on light sensitive paper. (T/E 1.2, 2.3)*

Grades 6–8, pages 67–68

Standard #3

- Use measurements of weight and volume to find out if several solid metal objects are made of the same metal or different metals. Explain why some of your conclusions may be more definite than others. Give reasons based on accuracy of measurements and on the physical properties of metals, where applicable.

Standard #4

- Carry out a chemical reaction. Determine the masses of all reactants and all products. Discuss whether results support the conservation of mass, taking into account the sensitivity and accuracy of measuring equipment used.
-

Appendix III

Historical and Social Context for Science and Technology/Engineering: Topics for Study

The following list of study topics is suggested for science and technology/engineering teachers who, together with their colleagues in social studies, history, economics, and other areas of study, may want to help students better understand the historical and social dimensions of science and technology/engineering. Study of these topics helps underline the extent to which scientific debate and technological change play a vital role in our local, regional, national, and international communities. Interested teachers should ensure that these topics are taught at appropriate grade levels and linked to content learning standards. The lists include suggestions for study only, and are not intended to be exhaustive in their scope.

I. The history of science

- Early and different attempts to understand the natural world
- Science and technology in the ancient world (e.g., China, Greece)
- The foundations for modern science in the 17th and 18th centuries
- The development of modern science in the 19th and 20th centuries
- Key figures, discoveries, and inventions (American and others) during the past four centuries
- Major theories that changed humans' view of their place in the world (e.g., the Copernican revolution and Darwin's Theory of Evolution)
- Social, religious, and economic conditions that supported or inhibited the development of science, technology, and/or engineering in various countries over the centuries

II. The nature of science

- Sources of the motivation to understand the natural world
- Basis in rational inquiry of observable or hypothesized entities
- Development of theories to guide scientific exploration
- Major changes in scientific knowledge that stem from new discoveries, new evidence, or better theories that account for anomalies or discrepancies
- Need to test theories, elimination of alternative explanations of a phenomenon, and multiple replications of results
- Tentativeness of scientific knowledge (Theories are the best we know from the available evidence until contradictory evidence is found.)

III. Benefits of science and technology/engineering

- Major advances in standards of living in the 19th and 20th centuries (e.g., communications, transportation)
- Continuous progress in personal and public health, resulting in increasing longevity
- Key discoveries and inventions and their beneficial uses (e.g., radium and the X-ray)

IV. Unintended negative effects from uses of science and technology/engineering

- How government, industry, and/or individuals may be responsible for negative effects (discuss examples here in Massachusetts, the United States, and abroad)

- Damage to the environment or ecosystems in this country and elsewhere (e.g., from pesticides, clearcutting, dumping of toxic wastes, overfishing, industrial reliance on soft coal for energy)
- Some sources of damage or pollution (e.g., human ignorance, overuse or abuse of natural resources)
- Unanticipated ethical dilemmas (e.g., genetic cloning, contraceptives)

V. How science and technology address negative effects from uses of science and technology/engineering

- Examples of products and systems that address negative effects (e.g., automobile emission control devices, ceramics in car glass, biodegradable plastic)
 - Costs and benefits of government regulations
 - How to balance risk-taking and creative entrepreneurial or academic activity with social, personal, and ethical concerns
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Appendix IV

Safety Practices and Legal Requirements

Safe practices are integral to teaching and learning of science and technology/engineering at all levels. It is the responsibility of each district to provide safety information and training to teachers and students, and the responsibility of each teacher to understand and implement safe laboratory practices. This section provides a description of the lab safety practices that are required by law, as well as resources that provide advice on general safety practices.

Legally Required Safety Practices

Safety Goggles

Wearing protective goggles in school laboratories is required by Massachusetts law. Massachusetts G.L. Chapter 71, 55C reads as follows:

Each teacher and pupil of any school, public or private, shall, while attending school classes in industrial art or vocational shops or laboratories in which caustic or explosive chemicals, hot liquids or solids, hot molten metals, or explosives are used or in which welding of any type, repair or servicing of vehicles, heat treatment or tempering of metals, or the milling, sawing, stamping or cutting of solid materials, or any similar dangerous process is taught, exposure to which may be a source of danger to the eyes, wear an industrial quality eye protective device, approved by the department of public safety. Each visitor to any such classroom or laboratory shall also be required to wear such protective device.

Thus, all individuals in the lab are required to wear goggles if they are using any of the materials or procedures listed in the statute. It is critically important for teachers to make students aware of the hazards of working with chemicals and open flame in the laboratory and other settings, and to be sure they wear goggles to protect their eyes. (Wearing protective goggles is also an OSHA standard – 1910.133.)

Treatment of Animals

Animals should be treated with care and dissection should be confined to the classroom and undertaken for academic purposes.

Massachusetts G.L. Chapter 272, 80G states:

No school principal, administrator or teacher shall allow any live vertebrate to be used in any elementary or high school under state control or supported wholly or partly by public money of the state as part of a scientific experiment or for any other purpose in which said vertebrates are experimentally medicated or drugged in a manner to cause painful reactions or to induce painful or lethal pathological conditions, or in which said vertebrates are injured through any other type of treatment, experiment or procedure including but not limited to anesthetization or electric shock, or where the normal health of said animal is interfered with or where pain or distress is caused.

No person shall, in the presence of a pupil in any elementary or high school under state control or supported wholly or partly by public money of the state, practice vivisection, or exhibit a vivisectioned animal. Dissection of dead animals or any portions

thereof in such schools shall be confined to the class room 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.

Live animals used as class pets or for purposes not prohibited in paragraphs one and two hereof in such schools shall be housed or cared for in a safe and humane manner. Said animals shall not remain in school over periods when such schools are not in session, unless adequate care is provided at all times.

The provisions of the preceding three paragraphs shall also apply to any activity associated with or sponsored by the school.

Whoever violates the provisions of this section shall be punished by a fine of not more than one hundred dollars.

For further discussion on the Board of Education's policy on the dissection of animals, please consult Appendix V.

Migratory Birds

Individuals are not allowed to acquire live or dead migratory birds, nests, or eggs, or to use them as lab animals.

Under federal law, 16 U.S.C. 703 (a) states:

[I]t shall be unlawful at any time, by any means or in any manner, to pursue, hunt, take, capture, kill, attempt to take, capture, or kill, possess, offer for sale, sell, offer to barter, barter, offer to purchase, purchase, deliver for shipment, ship, export, import, cause to be shipped, exported, or imported, deliver for transportation, transport or cause to be transported, carry or cause to be carried, or receive for shipment, transportation, carriage, or export, any migratory bird, any part, nest, or eggs of any such bird, or any product, whether or not manufactured, which consists, or is composed in whole or part, of any such bird or any part, nest, or egg thereof, included in the terms of the conventions between the United States and Great Britain for the protection of migratory birds concluded August 16, 1916 (39 Stat. 1702)

Thus, it is illegal to acquire any migratory bird, whether alive or dead, or their eggs or nests, for any purpose, including for use within a classroom or lab.

Mercury

Schools are not to have mercury, including equipment or materials containing mercury, on the premises (with limited exceptions), and any mercury-added products must be disposed of appropriately.

Massachusetts G.L., Chapter 21H, 6G (as amended by Chapter 190 of the Acts of 2006, effective October 1, 2006) states:

No school in the commonwealth shall purchase for use in a primary or secondary classroom elemental mercury, mercury compounds or mercury-added instructional equipment and materials, except measuring devices and thermometers for which no adequate nonmercury substitute exists that are used in school laboratories. This section shall not apply to the sale of mercury-added lamps or those products whose only mercury-added component is a mercury-added lamp or lamps.

Massachusetts G.L., Chapter 21H, 6I (as amended by Chapter 190 of the Acts of 2006, effective May 1, 2008) states:

(a) No person, household, business, school, healthcare facility or state or municipal government shall knowingly dispose of a mercury-added product in any manner other than by recycling, disposing as hazardous waste or using a method approved by the department [of environmental protection].

“Right to Know”

Individuals who work with hazardous chemicals have a “right to know” the dangers and nature of these chemicals.

Massachusetts G.L., Chapter 111F, 7 (a) states:

Except as otherwise provided by this section, an employer shall label with the chemical name each container in his or her workplace containing a toxic or hazardous substance. Said label shall also contain the proper NFPA [National Fire Protection Association] Code applicable to any contents of the container for which an NFPA Code has been published in NFPA 49, Hazardous Chemical Data, but only in those instances where the container contains more than five gallons or thirty pounds of materials to which the NFPA Code is applicable.

Thus, lab managers must make sure that all posters, labels, material safety data sheets, etc., describing and explaining the dangers of hazardous chemicals are clearly displayed and current.

Example of Safety Guidelines

Science staff should actively work to set safety policies, expectations, and classroom practices for their school and district. Example safety guidelines for the science classroom are included on the following pages to facilitate staff discussion. This example is excerpted from *Science and Safety: It's Elementary* (Council of State Science Supervisors), found at <http://www.csss-science.org/safety.shtml>. This is not necessarily a definitive list, nor does this constitute a definitive safety policy. This excerpt is included as an example for discussion and illustration.

1. Where can I find a general science safety checklist?

General Items

The following practices should be observed in your science instructional environment.

1. **Have and enforce** a safety contract signed by students and parents.
2. **Identify** medical and allergy problems for each student to foresee potential hazards.
3. **Assess and minimize** barriers for students with disabilities.
4. **Model, post, and enforce** all safety procedures. Display safety posters and the numbers for local poison control centers and emergency agencies.
5. **Know** district and state policies concerning administering first aid and have an adequately stocked first-aid kit accessible at all times.
6. **Report** all injuries, including animal scratches, bites, and allergic reactions, immediately to appropriate personnel.
7. **Be familiar with** your school's fire regulations, evacuation plans, and the location and use of fire fighting equipment.
8. **Post and discuss** emergency escape and notification plans/emergency phone numbers in each space used for science activity.
9. **Make certain** that the following items are easily accessible in elementary classrooms, classrooms with labs, and science resource rooms:
 - appropriate-size chemical splash goggles that are American National Standards Institute (ANSI) Z87 or Z87.1 coded and of type G, H, or K only
 - non-allergenic gloves
 - non-absorbent, chemical-resistant protective aprons
 - eyewash units
 - safety spray hoses/shower
 - ABC tri-class fire extinguisher(s)
 - flame retardant treated fire blanket
10. **Make certain** that you, your students, and all visitors are adequately protected when investigations involving glass (not recommended), heat, chemicals, projectiles, or dust-raising materials are conducted.

11. **Implement** a goggle sanitation plan for goggles used by multiple classes.

12. **Keep** spaces where science activities are conducted uncluttered.

13. **Limit** size of student working groups to a number that can safely perform the activity without causing confusion and accidents.

14. **Prepare** records (including Material Safety Data Sheets (MSDS) (See question 5) on all chemicals used) on safety training and laboratory incidents.

15. **Provide** adequate workspace (45 square feet) per student as well as low table sections for wheelchair accessibility that can be supervised by recommended ratio of teacher to student of 1:24.

16. **Do not permit** eating and drinking in any space where science investigations are conducted.

17. **Do not store**, under any circumstances, chemicals and biological specimens in the same refrigerator used for food and beverages.

18. **Do not use** mercury thermometers with elementary students, since their use is inappropriate. Any mercury thermometers still present should be disposed of properly.

Glassware Precautions

19. **Substitute** plasticware for glassware in elementary classrooms, classrooms with labs, and science resource rooms.

20. **Possess** a whiskbroom, dust pan, and disposal container for broken glass when using glassware of any type (not recommended).

21. **Make certain** that students understand they are not to drink from glass plasticware used for science experiments.

Chemical Precautions

22. **Label** equipment and chemicals adequately with respect to hazards and other needed information.

23. **Store** chemicals in appropriate places: e.g., in secured cabinet or stockroom, at or below eye level, on wooden shelves with a front lip, and without metal supports. Storage space should be kept cool, dry, and locked.



24. **Make certain** that students understand that chemicals must never be mixed "just for fun" or "to see what might happen"; that they should never taste chemicals; and that they should always wash their hands after working with chemicals.

Electrical Precautions

25. **Make certain** that students understand that they must NOT perform experiments with electrical current at home or at school "just for fun or to see what will happen." Only supervised activities directed by the teacher should be done.

26. **Make certain** electrical cords are short and plugged into the nearest socket. Emphasize that students grasp the plug, rather than the cord, when unplugging electrical equipment. Cords also must be in good repair. Do not use extensions.

27. **Be sure** that students' hands and surrounding surfaces are dry before plugging in electrical cords or turning on and off switches and appliances tools. Water can be a good conductor of electricity.

28. **Make sure** all electrical outlets are Ground-Fault Interrupters (GFI's). Cover outlets when not in use.

29. **Use** only three-prong (grounded) plugs when small electrical tools such as heating elements for terraria and aquaria, hot plates, or small motors are used. Extension cords **should not be used**.

30. **Instruct** students never to grasp any electrical device that has just been turned off, since it may be hot after use and result in serious burns.

31. **Make certain** that students understand that connecting only a wire between the terminals of a battery will result in the wire getting hot and possibly causing serious burns.

32. **Remind** students that even non-electrical hand tools such as hammers, screwdrivers, or hand drills slip easily and can produce projectiles or inflict serious cuts. Appropriate safety equipment **should always be worn**.

2. Where can I find a checklist of common laboratory operating procedures?

Regulated Safety Rules

- Know district, local, and state statutes and regulations regarding animal care, storage of chemicals, and fire safety. Does your district have a written Chemical Hygiene Plan? A district Science Safety Policy?
- Maintain Material Safety Data Sheets (MSDS) for all chemical supplies with a second set in the main office; generic chemicals and/or store-bought substances should also be listed in the inventory.
- Require the use of American National Standards Institute (ANSI) Z87.1 approved eye protective equipment (typically chemical splash safety goggles – types G, H, or K only), gloves, and aprons during all activities, including demonstrations in which chemicals, glassware, potential projectiles, or heat are used.
- Dispose of unwanted chemicals and materials according to state and local regulations.

General Safety Rules

- Know the safety hazards before starting an activity; you should do a “dry run” without the students to identify unforeseen hazards.
- Use only equipment that is in good working order; inspect equipment before each use.
- Maintain and have immediate access to a first-aid kit for emergency treatment (if local and state policies allow), as well as biohazard and chemical spill kits/materials.
- Never use unfamiliar chemicals unless MSDS sheets are consulted first. Consult MSDS and the container label before using chemicals for the first time.
- Never use mercury thermometers in elementary classrooms/labs.
- Prevent contamination by not returning unused chemicals to the original container.
- Label and date all storage containers of laboratory chemicals and preserved specimens upon receipt. Properly label all secondary chemical and specimen (set-nut) containers.
- Use unbreakable plastic equipment whenever possible; maintain a separate waste container for broken glass; sweep up broken glass with dustpan and brush.
- Check with school medical personnel at the beginning of the school year to identify student medical conditions such as allergies, epilepsy, etc.,

and be prepared to take appropriate actions.

- Check safety manuals for chemical and plant toxicity before use.

- Tie back long hair; secure loose clothing and dangling jewelry; do not permit open-toed shoes or sandals during lab activity. Clothing should cover upper and lower body.
- Wear appropriate protective eyewear for chemical and projectile hazards, as well as appropriate lab aprons and gloves.
- Never permit eating and drinking in the science classroom/laboratory.
- Advise students not to engage in a laboratory activity unless directed by you, and only after safety procedures are discussed and student “plans of action” (in inquiry) are reviewed and approved.
- Have students wash hands and clean nails directly after coming into contact with animals, plants, soil and water samples, chemical substances, and laboratory/work surfaces. Hands should always be washed upon completion of an inquiry activity.
- Teach students to pick up and transport a microscope with one hand under the base and one hand on the arm.

Classroom Management

- Supervise students at all times. Do not permit students to conduct unauthorized experiments or work unsupervised. Do not make assignments that require students to perform hazardous experiments at home.
- Maintain a clear view of all students at all times. Set up science learning centers for single students or small groups that allow easy observation of students. Periodically update and evaluate safety concerns in the centers.
- Do not block access to exits, emergency equipment, and utilities with personal items.
- Have students participate in determining classroom rules, laboratory safety procedures, and emergency action plans.
- Do not tolerate boisterous conduct (horseplay).
- Enforce established rules and procedures immediately and appropriately.
- Practice the procedures and rules yourself before expecting students to follow them, so you can identify unforeseen consequences and avoid liability.
- Discuss safety concerns with students prior to each laboratory activity and monitor students for compliance.



- Ensure that sight-impaired students are made familiar with and always use the same area and equipment. These students should be “huddled” with a student who can read instructions (if Braille forms or a tape recorder are not available) and guide him/her to safety in case of emergency.
- Model safety procedures prior to an activity and have students practice the procedures before beginning work.
- Use student safety contracts; have students and parents read and sign.
- Have an established procedure for student accident or injury: e.g., student runner, telephone/intercom, accident/injury report to the principal, etc.
- Lock science classrooms, cabinets, prep area doors, etc., when not in use; do not permit students in chemical/equipment storage rooms.
- Turn off gas and electrical equipment and close open containers during a fire drill. Gas, if available in the classroom, should always be turned off at the master valve when not in use.
- Have students report all accidents to the classroom teacher.
- Have students check the classroom daily for safety hazards.
- Use only age-appropriate activities with students.
- Have a designated “broken glass” container, if you use equipment made of glass (NOT recommended).
- Limit the size of student working groups to a number that can safely perform the activity without causing confusion and accidents.
- Display commercial and/or student-made safety posters and classroom safety rules in the classroom.
- Do not permit elementary students to dispense chemicals or handle containers of hot liquids.
- Discourage tasting and smelling. When smelling is required, students should waft vapors toward their nose using their hand. They should never inhale the vapors directly.
- Dispose of all waste chemicals properly. There should be separate containers for each solid. Non-hazardous liquids/solutions should be rinsed down the drain one at a time and flushed with plenty of water.
- Clean up spills or ice immediately on tables and floor; take appropriate precautions against contamination as needed.
- Have students clean up their work areas at the completion of each day’s activity, including sinks and floor.

Additional Resources

1) General Safety Advice

Several websites provide lists of general safety guidelines. While these practices are commonly accepted, they are not officially endorsed by the Massachusetts Department of Education:

- The Council of State Science Supervisors' safety website, <http://www.csss-science.org/safety.shtml>
- Sargent-Welch, www.sargentwelch.com/html/pdfs/ScienceandSafety.pdf
- Flinn Scientific, www.flinnsci.com
- Laboratory Safety Institute, www.labsafety.org
- National Institutes of Health (NIH), www.nih.gov/od/ors/ds/index.html
- U.S. Department of Labor: Occupational Safety & Health Administration (OSHA), www.osha.gov

2) OSHA Regulations

The U.S Department of Labor, Occupational Safety & Health Administration (OSHA) has issued regulations for laboratory safety in the workplace that would be highly recommended for schools. The relevant OSHA regulations include the following (regulation numbers appear in parentheses):

- Limiting the exposure to hazardous chemicals (1910.1450)
(http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10106)
 - Lab managers should have a chemical hygiene plan, ensure that the proper protective gear is used, provide training for those working in the lab, etc.
- Limiting the exposure to blood-borne pathogens (1910.1030)
(http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10051)
 - Lab managers should have an Exposure Control Plan, provide hand washing facilities; ensure that lab workers wash hands right after the removal of gloves; dispose of contaminated needles and other sharp instruments in puncture-proof, non-leak containers; prohibit the application of cosmetics, changing of contact lenses and other such practices in the lab; provide proper protective eye, hand, and face protecting equipment, etc
- Providing information about the hazardous chemicals in use in the lab (1910.1200)
(http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10099)
 - 1910.1200 (b) (1): All employers [must] provide information to their employees about the hazardous chemicals to which they are exposed, by means of a hazard communication program, labels and other forms of warning, material safety data sheets, and information and training.
- Using hand protection when handling potentially dangerous substances (1910.138)
(http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9788)
 - 1910.138 (a): Employers shall select and require employees to use appropriate hand protection when employees' hands are exposed to hazards such as those from skin absorption of harmful substances; severe cuts or lacerations; severe abrasions; punctures; chemical burns; thermal burns; and harmful temperature extremes.

- 1910.138 (b): Employers shall base the selection of the appropriate hand protection on an evaluation of the performance characteristics of the hand protection relative to the task(s) to be performed, conditions present, duration of use, and the hazards and potential hazards identified.

3) Safe Handling of Animals in General

- Institute for Laboratory Animal Research (ILAR): *Principles and Guidelines for the Use of Animals in Precollege Education*, http://dels.nas.edu/ilar_n/ilarhome/Principles_and_Guidelines.pdf
- Mid-Continent Association for Agriculture, Biomedical Research and Education (MAABRE), *Do's and Don'ts of Using Animals in the Classroom*, http://www.maabre.org/animals_classroom.htm

4) Bird Carcasses

Teachers should not take bird carcasses found in the environment and use them for lab work. This practice spreads bird-borne diseases. For more information, check the following websites:

- The Massachusetts Department of Public Health's website, http://www.mass.gov/dph/cdc/epii/flu/avian_flu_fa.pdf
- The Centers for Disease Control website, <http://www.cdc.gov/healthypets/animals/birds.htm>

5) Safety Contract Examples

- www.flinnsci.com/Documents/miscPDFs/Safety_Contract.pdf
- www.labsafety.org/pdf/Student_Safety_Contract.pdf
- sun.menloschool.org/~tbuxton/chembio/safety.html

6) Safe Handling of Chemicals

- Massachusetts Department of Environmental Protection (DEP), *Massachusetts School Chemical Management Program Manual*, <http://www.mass.gov/dep/service/schlchem.pdf>
- Massachusetts Department of Labor, Division of Occupational Safety, *School Laboratory Safety for Teachers and Laboratory Supervisors*, <http://www.mass.gov/dos/iaqdocs/iaq-403.htm>
- American Chemical Society, *Safety for Introductory Chemistry Students*, http://membership.acs.org/ccs/pubs/safety_for_intr_chem.pdf

For more information on the dangers of mercury, see

- Massachusetts Department of Environmental Protection (DEP), *Municipal Collections of Mercury*, http://www.cetonline.org/FarmBusiness/municipal_collections_of_mercury.htm#school

7) Latex Balloons

Latex balloons are a choking hazard for small children, and students of any age may have an allergic reaction to latex. For more information, check the following websites:

- The American Academy of Family Physicians,
<http://www.aafp.org/afp/980101ap/reddy.html>
 - The Health and Safety Executive site, <http://www.hse.gov.uk/latex/about.htm>
 - American Latex Allergy Association,
http://www.latexallergyresources.org/ResourceManual/section5/balloons_busted-jsonline.cfm
 - The Balloon Council's website,
<http://www.balloonhq.com/BalloonCouncil/facts.html>
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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: _____

Appendix VI

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>

Appendix VII

Criteria for Evaluating Instructional Materials and Programs in Science and Technology/Engineering

	STRONGLY AGREE	AGREE	CANNOT JUDGE	DISAGREE	STRONGLY DISAGREE
I. Scientific and Technological Contents					
Reflect the learning standards in the <i>Science and Technology/Engineering Curriculum Framework</i>					
Are scientifically and technologically accurate					
II. Features					
Provide descriptions of the achievements of historically important scientists and engineers					
Contain illustrations of contemporary children and adults that reflect the diversity of our society					
Include clear instructions on using tools, equipment, and materials, and on how to use them safely in learning activities					
Include a master source of materials and resources					
Provide student texts, booklets, or printed material and accompanying teacher manuals					
Provide coherent units that build conceptual understanding					
Provide for in-depth investigations of major scientific, technological, and engineering concepts					
Incorporate applications of science, technology, and engineering					
Highlight connections within science, technology, and engineering, and with mathematics and social sciences where relevant					
III. Learning Activities					
Involve students in active learning and inquiry					
Clarify appropriate use of instructional technology such as calculators and computers					
Show how instructional technology can help students visualize complex concepts, analyze and refine information, and communicate solutions					
Provide multiple ways for students to explore concepts and communicate ideas and solutions					
Are developmentally appropriate and provide for different abilities and learning paces					
Encourage discussion and reflection					
Draw on a variety of resources (e.g., trade manuals, measuring tools, other tools and machines, manipulatives, the Internet)					

	STRONGLY AGREE	AGREE	CANNOT JUDGE	DISAGREE	STRONGLY DISAGREE
IV. Teacher Support Materials					
Provide a clear conceptual framework for the concepts and skills taught					
Offer ideas for involving parents and community, and keeping them informed about the programs					
Give suggestions for a variety of pedagogical strategies, such as open-ended questioning, direct instruction, practice, discussion, and cooperative learning					
Reference resource materials, such as appropriate videos, file clips, reference books, software, video laser discs, long-distance learning, CD-ROMs, and electronic bulletin boards					
Suggest how to adapt materials for students with differing levels of achievement					
Suggest enrichment and skill reinforcement activities for extended learning					
Include suggestions for a variety of assessment approaches such as portfolios, journals, projects, and informal and formal tests					
V. Student Assessment Materials					
Are free of inappropriate or derogatory material					
Occur throughout the unit, not just at the end					
Incorporate multiple forms of assessment, such as oral presentations, written reports, teacher observations, performance assessments, quizzes, and pre- and post-tests					
Focus on the acquisition of skills and concepts as well as on the learning process					
VI. Program Development and Implementation					
Have field test data showing positive effects on student learning					
Are adaptable to local curriculum and/or school					
Offer training and long-term follow-up for teachers					

References

Glossary of Selected Science and Technology/Engineering Terms

Adaptation A modification of an organism or its parts that makes the organism more fit for existence under the conditions of its environment.

Atmosphere The gaseous envelope of a celestial body (as a planet).

Biotechnology Any technique that uses living organisms, or parts of organisms, to make or modify products, improve plants or animals, or to develop microorganisms for specific uses.

Climate The average course or condition of the weather at a place, usually over a period of years, as exhibited by temperature, wind velocity, and precipitation.

Communication The successful transmission of information through a common system of symbols, signs, behavior, speech, writing, and/or signals.

Conductor A material capable of transmitting energy (e.g., heat, sound, electricity).

Constraint A limit to the design process. Constraints may be such things as appearance, funding, space materials, or human capabilities.

Construction The systematic act or process of building, erecting, or constructing buildings, roads, or other structures.

Consumer An organism requiring complex organic compounds for food that it obtains by preying on other organisms or by eating particles of organic matter.

Decomposer Any of various organisms (e.g., many bacteria and fungi) that return constituents of organic substances to ecological cycles by feeding on and breaking down dead protoplasm.

Design An iterative decision-making process that produces plans by which resources are converted into products or systems that meet human needs and/or wants, or that solve problems.

Design brief A written plan that identifies a problem to be solved, its criteria, and its constraints. The design brief is used to encourage consideration of all aspects of a problem before attempting a solution.

Design process A systematic problem-solving strategy, with criteria and constraints, used to develop many possible solutions to solve a problem or satisfy human needs and/or wants, and to narrow down the possible solutions to one final choice.

Ecosystem A community of organisms and their environment, functioning as an ecological unit.

Electric circuit The complete path of an electric current, usually including the source of electric energy.

Electric current A flow of electric charge.

Energy The capacity for doing work.

Engineer A person who is trained in and uses technological and scientific knowledge to solve practical problems.

Engineering A profession involving the knowledge of mathematical and natural sciences (biological and physical) gained by study, experience, and practice, applied with judgement and creativity to develop ways to utilize the materials and forces of nature for the benefit of human-kind; work performed by an engineer.

Engineering design The systematic and creative application of scientific and mathematical principles to practical ends, such as the design, manufacture, and operation of efficient and economical structures, machines, processes, and systems.

Environment The complex of physical, chemical, and biotic factors (e.g., climate, soil, living things) that act upon an organism or an ecological community and ultimately determine their forms and survival.

Erosion The gradual wearing away of rock or soil by physical breakdown, chemical solution, and/or transportation of material, as caused, for example, by water, wind, or ice.

Food chain An arrangement of the organisms of an ecological community according to the order of predation, in which each uses the next, usually lower, member as a food source.

Force An agency or influence that, if applied to a free body, results chiefly in an acceleration of the body and sometimes in elastic deformation or other effects.

Fossil A remnant, impression, or trace of an organism of a past geologic age that has been preserved in the earth's crust.

Gas/gaseous state Gas is a state of matter. Gas molecules do not hold together at all, so gas spreads out in all directions, including straight up. Gas changes both its shape and its volume very easily.

Habitat The place or environment where a plant or animal naturally or normally lives and grows.

Heat The energy associated with the random motions of the molecules, atoms, or smaller structural units of which matter is composed.

Igneous Formed by solidification of magma.

Inherited To receive from ancestors by genetic transmission.

Insulator A material that is a poor conductor of electricity, heat, or sound.

Life cycle The series of stages in form and functional activity through which an organism passes between origin and expiration.

Light An electromagnetic radiation in the wavelength range including infrared, visible, ultraviolet, and X-rays, traveling in a vacuum with a speed of about 186,281 miles (300,000 kilometers) per second; *specifically*: the part of this range that is visible to the human eye.

Liquid/liquid state Liquid is a state of matter. Liquid molecules hold together weakly, so liquids flow. Liquids do not change their volumes significantly but do change their shapes easily.

Machine A device with fixed and moving parts that modifies mechanical energy in order to do work.

Magnet An object that can attract certain metals, such as iron and nickel. It can also attract or repel another magnet, or the mineral lodestone. All magnets have a north-seeking pole and a south-seeking pole.

Magnetic field Magnets and wires carrying electric current have a magnetic field. Magnetic fields interact to produce a force of attraction or repulsion.

Manufacturing The process of making a raw material into a finished product, especially in large quantities.

Material The tangible substance (chemical, biological, or mixed) that goes into the makeup of a physical object. One of the basic resources used in a technological system.

Matter, states of Matter ordinarily exists in one of three physical states: solid, liquid, or gas. A given object's state depends on what the molecules are doing at the object's current temperature and pressure, i.e., Are the molecules not holding together at all, holding together weakly, or holding together so tightly that they are locked into a stationary position? The transition between the states occurs at definite temperatures and pressures. A fourth state of matter, plasma (ionized gas in which the electrons are separated from the nuclei), can exist at extremely high temperatures. Plasma is found on the sun and other stars.

Medium A substance regarded as the means of transmission for a force or effect.

Metamorphic rocks A rock formed from preexisting rocks that were subjected to very high pressure and temperature, resulting in their structural and chemical transformation.

Metamorphosis A marked and more or less abrupt developmental change in the form or structure of an animal (e.g., butterfly or frog) occurring subsequent to birth or hatching.

Mineral A solid homogeneous crystalline chemical element or compound that results from the inorganic processes of nature.

Natural material Material found in nature, such as wood, stone, gases, and clay.

Orbit A path described by one body in its revolution about another (e.g., Earth about the sun, an electron about an atomic nucleus).

Organism An individual self-sustaining unit of life or living material. Five forms of organisms are known: plants, animals, fungi, protists, and bacteria.

Pitch The property of a sound, and especially a musical tone, that is determined by the frequency of the waves producing it: highness or lowness of sound.

Plasma/plasma state Plasma is a state of matter, often called "the fourth state." The atoms in plasma move around in all directions at high speed. Plasmas are usually very hot and they glow. The sun, northern lights, lightning, and the glowing "gases" in neon sign tubes and fluorescent lamp tubes are examples of plasmas.

Precipitation A deposit on the earth of hail, mist, rain, sleet, or snow; *also*: the quantity of water deposited.

Process 1. Human activities used to create, invent, design, transform, produce, control, maintain, and use products or systems; 2. A systematic sequence of actions that combines resources to produce an output.

Producer Any of various organisms (e.g., a green plant) that produce their own organic compounds from simple precursors (e.g., carbon dioxide and inorganic nitrogen), and many of which are food sources for other organisms.

Property A characteristic, attribute, or trait of an object.

Prototype A full-scale working model used to test a design concept by making actual observations and necessary adjustments possible.

Reflection The return of light or sound waves from a surface.

Refraction Deflection from a straight path undergone by a light ray or energy wave in passing obliquely from one medium into another (e.g., from air into glass), in which its velocity changes.

Resource In a technological system, the basic technological resources are energy, capital, information, machines and tools, materials, people, and time.

Revolve To move in a curved path around a center or axis.

Rotate To turn about an axis or a center.

Sedimentary Rocks formed from materials deposited as sediment by water, wind, or ice, including debris of organic origin, and then compressed and cemented together by pressure.

Simple machines The simple machines are the lever, pulley, and inclined plane, along with their most basic modifications, the wheel and axle, wedge, and screw. A complex machine is a machine made up of two or more simple machines.

Sketch A rough drawing that represents the main features of an object or scene that is often made as a preliminary study.

Solar system The sun together with the group of celestial bodies that are held by its attraction and revolve around it.

Solid/solid state Solid is a state of matter. Solid molecules hold together very tightly and often line up in exact patterns, therefore, solids do not flow. Solids do not change their shapes or volumes.

Sound A kind of energy contained in vibrating matter. Sound travels through solids, liquids, and gases. The eardrums convert this vibrational energy into signals that travel along nerves to the brain, which interprets them as voices, music, noise, etc.

Streak The color of the fine powder of a mineral obtained by scratching or rubbing against a hard white surface and constituting an important distinguishing characteristic. Note: the streak color may be completely different from the color observed at the surface of the mineral.

Synthetic material Material that is not found in nature (e.g., glass, concrete, plastics).

System A group of interacting, interrelated, or interdependent elements or parts that function together as a whole to accomplish a goal.

Technology 1. Human innovation in action that involves generating knowledge and processes to develop systems that solve problems and extend human capabilities; 2. The innovation, change, or modification of the natural environment to satisfy perceived human needs and/or wants.

Technology education The study of technology, which provides an opportunity for students to learn about the processes and knowledge related to technology that are needed to solve problems and extend human capabilities.

Texture The nature of the surface of an object, especially as described by the sense of touch, but excluding temperature. Textures include rough, smooth, feathery, sharp, greasy, metallic, and silky.

Weather The state of the atmosphere with respect to heat or cold, wetness or dryness, calm or storm, clearness or cloudiness.

Weight The force with which a body is attracted toward the earth or a celestial body by gravitation, and which is equal to the product of the mass and the local gravitational acceleration.

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Selected Websites for Science and Technology/Engineering Education

General Science and Technology/Engineering Resources	Website
AAAS, Project 2061	www.project2061.org/research/curriculum.htm
Ask a Scientist (U.S. Department of Energy-Office of Science Education)	newton.dep.anl.gov/aasquest.htm
Center for Improved Engineering & Science Education	www.k12science.org
Center for STEM Education at Northeastern University	www.stem.neu.edu
Discovery School	school.discovery.com/
Eisenhower National Clearinghouse for Mathematics and Science Education	www.goenc.com/
Exploratorium	exploratorium.edu
Flinn Scientific	flinnsci.com
Futures Channel, The	www.thefutureschannel.com
Jason Project, The	jasonproject.org
Knowledge Loom, The	knowledgeloom.org
Laboratory Safety Institute	labsafety.org
Massachusetts Department of Education	www.doe.mass.edu
<i>Curriculum Frameworks</i>	www.doe.mass.edu/frameworks/current.html
Massachusetts Comprehensive Assessment System (MCAS)	www.doe.mass.edu/mcas/
Massachusetts Online Network for Education (MassONE) – searchable standards, lesson plan tools	massone.mass.edu/
Museum Institute for Teaching Science (MITS, Inc.) List of museums, zoos, aquariums, etc.	www.mits.org www.mits.org/resources.htm
NASA Classroom of the Future	www.cotf.edu/
NASA Education	www.education.nasa.gov
NASAexplores (lessons and articles based on current research and developments)	www.nasaexplores.com/index.php
NASA’s Kids Science News Network (KSNN) (Grades K–5)	ksnn.larc.nasa.gov/home.html
National Assessment of Educational Progress (NAEP)	nces.ed.gov/naep3/
National Partnership for Quality Afterschool Learning	www.sedl.org/afterschool/guide/science/
National Science and Technology Week	nsf.gov/od/lpa/nstw/start.htm
National Science Education Standards	www.nap.edu/readingroom/books/nses/html/
National Science Foundation	www.nsf.gov
Public Broadcasting System’s (PBS) TeacherSource database	pbs.org/teachersource/
Sargent-Welch: General Space Guidelines (for Laboratories) Safety/Teachability Review	sargentwelch.com/article.asp?ai=21 sargentwelch.com/article.asp?ai=23
Teachers’ domain (media learning tools, lesson plan tools, professional development courses)	www.teachersdomain.org
TE-MAT (teacher education material reviews for science and math professional development)	www.te-mat.org
TERC (mathematics, science, and technology/engineering curriculum programs)	terc.edu
Trends in International Mathematics and Science Study (TIMSS)	nces.ed.gov/timss/

General Science and Technology/Engineering Resources (cont.)		Website
Vermont Institutes		www.vermontinstitutes.org
Wright Center for Science Education, Tufts University		www.tufts.edu/as/wright_center/
Earth and Space Science		Website
Center for International Earth Science Information Network (CIESIN)		www.ciesin.org/
Christa Corrigan McAuliffe Center for Education and Teaching Excellence		www.christa.org
Incredible Journey/Project WET		www.montana.edu/wwwwet/journey.html
Learning Adventures in Environmental Science		www.bellmuseum.org/distancelearning/belllive.html
Massachusetts Envirothon		www.maenvirothon.org/
NASA's Mars Exploration Program		mars.jpl.nasa.gov
Private Universe Project, The (The Annenberg/CPB Math and Science Project)		www.learner.org/teacherslab/pup/index.html
Life Science (Biology)		Website
Biodiversity Days (Massachusetts Association of Conservation Commissions)		www.maccweb.org/biodiversity_days.html
Biology resources list		www.educationindex.com/biology/
Food Science and Technology		www.foodscience.unsw.edu.au/
Resources for Food Science		members.tripod.com/~kburge/HomeEc/foodscience.html
U. S. Food and Drug Administration - Center for Food Safety and Applied Nutrition		vm.cfsan.fda.gov/~dms/educate.html#educators
Physical Sciences (Physics and Chemistry)		Website
Amusement park physics		www.learner.org/exhibits/parkphysics/
Hands on Plastic		www.teachingplastics.org/
Links for Chemistry Teachers		www.chemistrycoach.com/links_for_chemistry_teachers.htm
Physics Teaching Resource Agents (PTRA) (American Association of Physics Teachers)		aapt.org/PTRA/index.cfm
Technology/Engineering		Website
Building Big, the PBS series		www.pbs.org/wgbh/buildingbig/
Design It! Engineering in After School Programs		cse.edc.org/products/curricula/designit/default.asp
Discover Engineering		discoverengineering.org
Education Development Center, Inc. (science and technology/engineering projects)		edc.org
FIRST (For Inspiration and Recognition of Science & Technology) Lego League (integrates robotics technology into the LEGO building system)		mindstorms.lego.com/
FIRST Robotics Competition		www.usfirst.org/
How Stuff Works		howstuffworks.com
Internet Science Technology Fair		istf.ucf.edu/
Journal of Technology Education		scholar.lib.vt.edu/ejournals/JTE/
Junior Engineering Technical Society (JETS)		www.jets.org
Massachusetts Institute of Technology's <i>Technology Review</i>		www.techreview.com
Museum of Science		www.mos.org
National Center for Technological Literacy (NCTL)		www.mos.org/doc/1505
National Engineers Week Future City Competition		futurecity.org

Technology/Engineering (cont.)	Website
Preview of The New York State Department of Education's 8 th -Grade Technology assessment	www.emsc.nysed.gov/ciai/mst/techedtest/online.html
Project Lead the Way	www.pltw.org/aindex.htm
Tech Directions Online	www.techdirections.com
Technology Student Association	www.tsaweb.org/
TechWeb	www.techweb.com
TryEngineering	www.tryengineering.org
United States Department of Transportation	www.dot.gov
Science and Technology/Engineering Teacher Associations and Networks	Website
American Association of Physics Teachers	aapt.org
American Society for Engineering Education	www.asee.org
Association for Science Teacher Education: Northeast Building a Presence for Science	umassk12.net/pvnet/ASTENE/science.nsta.org/bap/
Chemistry Teacher Support Group	hschem.org
International Technology Education Association	iteaconnect.org
Massachusetts Association of Science Teachers	mast.nu
Massachusetts Association of Conservation Commissions	www.maccweb.org/
Massachusetts Biotechnology Education Foundation	www.massbio.org/massbioed/index.php
Massachusetts Earth Science Alliance	mesa.terc.edu/index.html
Massachusetts Environmental Education Society	www.massmees.org
Massachusetts Marine Educators	massmarineeducators.org/index.php
Massachusetts Science Education Leadership Association	msela.org/
Massachusetts Technology Education/Engineering Collaborative	masstec.org/
National Association of Biology Teachers	nabt.org
National Earth Science Teachers Association	www.nestanet.org
National Science Teachers Association	nsta.org
New England Association of Chemistry Teachers	neact.org
Science, Technology, Engineering, and Mathematics Teacher Education Collaborative	k12s.phast.umass.edu/~stemtec/
Secretaries Advisory Group on Environmental Education	sagee.org
Technology Education Association of Massachusetts	www.awrsd.org/team/

