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Massachusetts Science and Technology/Engineering Curriculum Framework



May 2001



The Commonwealth of Massachusetts Department of Education

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David P. Driscoll
Commissioner of Education

May 2001

Dear Colleagues,

I am pleased to present to you the 2001 Massachusetts Science and Technology/Engineering Curriculum Framework. This framework presents the revised statewide guidelines for learning, teaching, and assessment in science and technology/engineering for the Commonwealth's public schools. Based on scholarship, sound research, and effective practice, the framework will enable teachers and administrators to strengthen curriculum and instruction from prekindergarten through grade 12.

I am proud of the work that has been accomplished. The comments and suggestions received on the 1995 Science and Technology Curriculum Framework, as well as on working drafts of this version, have strengthened this framework. The major changes from the 1995 framework to the May 2001 document include the following:

- Standards are more specific, to enable teachers to design instruction and assessment more effectively. Grade spans have narrowed from PreK-4, 5-8, 9-10 to PreK-2, 3-5, 6-8, 9-10.
- The four strands in the 1995 document (Inquiry, Domains of Science, Technology and Science, and Technology and Human Affairs) are now four content strands (Earth and Space Science, Life Science, Physical Sciences, and Technology/Engineering). "Inquiry" is now to be taught with the content of each domain of science.
- High school standards: The 2001 framework has a set of standards for comprehensive, full year courses in each of the four science domains, and in Technology/Engineering. In each domain, a subset of these standards has been identified as core. Only core standards will be assessed by MCAS. In addition, a set of core standards has been identified for a two-year, grade 9 and 10 integrated science program. These standards are a subset of the core standards from each of the four science domains.

- Format: The revised document has a three-column grid for grades PreK-5 that shows the topic and the Learning Standards, Ideas for Developing Investigations and Learning Experiences, and Suggested Extensions to Learning in Technology/Engineering.
- A glossary was added for selected terms and a topical outline was included.

From December 2000 to May 2001 the framework underwent an intensive review for scientific and technological accuracy. The wording was revised and specific examples were added to help clarify the learning standards. Changes at this final stage of review include the following:

- For grades PreK-2, students' sense of geologic time is strengthened in the earth science strand with the standard "Recognize that fossils provide us with information about living things that inhabited the earth years ago."
- Life science standards in the lower and middle grades were strengthened and made more specific to develop concepts of evolution, including adaptation, heredity, and comparison of organisms.
- Based on significant feedback from teachers, the focus on plants and animals in grades 6-8 was extended to include a standard that specified the human organism as a set of systems that interact with each other.
- The description of the taxonomic system was sharpened by including in the standards for grades 6-8 the classification of organisms into "the *currently recognized* kingdoms."
- At the high school level, we recognized the growing importance of molecular biology by adding the standard asking students to "Describe the processes of replication, transcription, and translation and how they relate to each other in molecular biology."
- In the physics standards, plasma was specified as the fourth state of matter.

We will continue to work with schools and districts to implement the 2001 Science and Technology/Engineering Curriculum Framework over the next several years, and we encourage you to send us your comments as you use it. All of the curriculum frameworks are subject to continuous review and improvement for the benefit of the students of the Commonwealth.

Thank you again for your ongoing support and for your commitment to achieving the goals of education reform.

Sincerely,



David P. Driscoll
Commissioner of Education

Acknowledgments

The 2001 Science and Technology/Engineering Curriculum Framework is the result of the contributions of many educators across the state. 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 Science and Technology/Engineering Curriculum Framework is available on-line at the Department's website (www.doe.mass.edu/frameworks/current.html). The Word and PDF files are the same as this printed version. The HTML file is a dynamic version that is continually being updated with new examples and vignettes that are linked directly to the learning standards. If you would like to contribute an example or vignette that has been successful in your classroom, please contact the Office of Mathematics, Science, and Technology/Engineering at (781) 338-3483.

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Introduction

The Massachusetts Science and Technology/Engineering Curriculum Framework is one of seven curriculum frameworks that advance Massachusetts's 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, by college and university professors, and by engineers and scientists in the various domains working with staff from the Department of Education. Its purpose is to guide teachers and curriculum coordinators about what content should be taught from PreK through high school.

Organization of the document

The guiding principles present a set of tenets about effective PreK–12 programs and instruction in science and technology/engineering. These principles articulate ideals of teaching, learning, assessing, and administering science and technology/engineering programs in Massachusetts. They show how educators may create educational environments characterized by curiosity, persistence, respect for evidence, open-mindedness balanced with skepticism, and a sense of responsibility.

The strands organize the content areas into earth and space science, life science (biology), the physical sciences (physics and chemistry), and technology/engineering. Each strand details the essential knowledge and skills that students should acquire through the grades. The learning standards within each strand are organized by grade span and grouped by subject area topics. Following the topics at the high school level are broad concepts to which the learning standards are related. The standards outline specifically what students should know and be able to do at the end of each grade span.

For grades PreK–5, the standards are accompanied by ideas for developing investigations and learning experiences in science and by extensions to learning in technology/engineering. These latter activities are coded to the PreK–5 technology/engineering standards. Additional activities to enhance the PreK–8 learning standards are found in Appendix III.

For grades 6–8, the science standards are accompanied by examples of sound science-based learning experiences. There are no extensions to technology/engineering associated with the science learning standards at this level because technology education is configured as a separate course in grades 6–8. Examples of learning activities for standards in the technology/engineering strand are included with the technology/engineering standards.

For grade 9 and higher, learning standards are listed for full first-year courses in earth and space science, biology, physics, chemistry, and technology/engineering. Core standards are in boldface type in each set of standards. From each set of core standards in the four sciences, a subset has been chosen for a two-year integrated science sequence in grades 9 and 10 (shown in Appendix II).

At the high school level, the Department will provide discipline-specific assessment options based on the core standards in earth and space science, biology, chemistry, physics, and technology/engineering. The Department will also offer an assessment for the two-year integrated science course sequence in grades 9 and 10 based on the subset of standards chosen for it. Districts will decide what assessment options to provide their students based on the courses they offer in grade 9 and higher.

Development of the standards

This framework derives from two reform initiatives in Massachusetts, the Education Reform Act of 1993 and Partnerships Advancing the Learning of Mathematics and Science (PALMS). Since 1992, the PALMS Statewide Systemic Initiative has been funded by the National Science Foundation in partnership with the state and the Noyce Foundation. Of the seven initial goals for this initiative, the first was to develop, disseminate, and implement curriculum frameworks in mathematics and in science and technology. The initial science and technology framework was approved in 1995, and was implemented in the field.

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 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, 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 developed a comprehensive set of standards for a course in each domain from which core standards were chosen for discipline-specific assessments. Groups of technology/engineering educators also contributed to the development of a comprehensive set of standards and core standards for the technology/engineering course at the high school level.

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, habits, and subject matter knowledge for informed participation in the intellectual and civic life of American society, and for further education in these areas if they seek it.

The nature of science

Science may be described as attempts 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 provides 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, and innumerable other examples of technology/engineering, emerges from the scientific knowledge, imagination, persistence, talent, and ingenuity of its practitioners. Each technology represents a designed solution, usually created in response to a specific practical problem. As with science, direct engagement with the phenomena in question is central to the definition of these problems and their successful solution.

The relationship between science and technology/engineering

In spite of their different ends, 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 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 improvement of the internal combustion engine, power transformers, nuclear power, and human gene therapy. In some of the most sophisticated efforts of scientists and engineers, the boundaries are so blurred that the designed device allows us to discern heretofore unnoticed natural patterns while the accounting for those patterns makes it possible to continue to develop the device. In these instances, scientists and engineers are engaged together in extending knowledge.

Inquiry and Experimentation

Asking and pursuing questions are keys to learning in all academic disciplines. There are multiple ways that students can ask and pursue questions in the science class. One way is to explore scientific phenomena in a classroom laboratory or around the school. Classroom investigation and experimentation can build essential scientific skills such as observing, measuring, replicating experiments, manipulating equipment, and collecting and reporting data. Students may sometimes choose what phenomenon to study, e.g., for a science fair project. More often, they conduct investigations and experiments that are selected and guided by the teacher.

Students can also examine the questions pursued by scientists in their 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 the 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 and explanatory diagrams and textbooks.

Scientific inquiry and experimentation should not be taught or tested as separate, stand-alone skills. Rather, opportunities for inquiry and experimentation should arise within a well-planned curriculum in the domains of science. They should be assessed through examples drawn from the life, physical, and earth and space science standards so that it is clear to students that in science, *what* is known does not stand separate from *how* it is known.

In the earliest grades, 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 would write down what happens over time in their own words.

In the later elementary years, 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 begin to incorporate the mathematical skills of measuring and graphing to communicate their findings.

In the middle school years, teacher guidance remains important but allows for more variations 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 V). At the conclusion of their investigations, students at the middle school level can be expected to prepare formal 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.

Skills of Inquiry

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

- Pose questions and state hypotheses based on prior scientific observations, experiments, and knowledge.
- Distinguish between hypothesis and theory as scientific terms.
- Either individually or as part of a student team, design and complete a scientific experiment that extends over several days or weeks.
- Use mathematics to analyze and support findings and to model conclusions.
- Simulate physical processes or phenomena using different kinds of representations.
- Identify possible reasons for inconsistent results, such as sources of error or uncontrolled conditions.
- Revise scientific models.
- Communicate and defend a scientific argument.

Guiding Principles

G U I D I N G P R I N C I P L E 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. The purpose of this framework is to delineate what knowledge is essential if students are to attain understanding of basic scientific concepts before graduation from high school.

Students in grades PreK–5 should have science instruction on a regular basis every year. Approximately one-quarter of their science time in PreK–5 should be devoted to technology/engineering. In middle school, they should have a full year of science study every year. Within the grades 6–8 span, students should also have one year of technology/engineering education in addition to 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 courses, and in grades 11 and 12, they should take more science courses or pursue advanced study in science through advanced placement courses, independent research, or study of special topics. In technology/engineering at the high school level, students may take semester- or year-long coursework in this area to complement or extend their study of science and mathematics.

G U I D I N G P R I N C I P L E I I

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 concern. Taken together, they present a coherent view of the world. 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 then 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 level, 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 science 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 analysis 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 more simple 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.

Because of the importance of mathematics to science and technology/engineering, all teachers, curriculum coordinators, and others who help implement this framework must be aware of the level of mathematical knowledge needed for each science course at the high school level and ensure that the appropriate mathematical knowledge has already been taught or, at the least, 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 may make sense to the students, and the 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 find a variety of ingenious ways of reconciling their 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 context for an experiment, guide student activities, and help students focus on important ideas and concepts.

Puzzlement and uncertainty are common features in experimentation. Students need time to examine their ideas as they learn how to apply them to 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.

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

GUIDING PRINCIPLE VI

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 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.

GUIDING PRINCIPLE VII

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

Assessment assists teachers in improving classroom practice, planning curricula, developing self-directed learners, and reporting student progress. 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. In essence, assessment reflects classroom expectations and shows the outcomes of student learning.

Assessments come in many forms. These 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. 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 framework's learning standards are a key resource for setting knowledge and performance standards. In helping students achieve standards, teachers should use a variety of question formats: short answer, multiple choice, and open ended. They should also develop

performance-based assessments that allow students to demonstrate what they have learned in the context of solving a complex problem. This kind of assessment requires students to refine a problem, devise a strategy to solve it, conduct sustained work, and deal with both complex concepts and discrete facts.

GUIDING PRINCIPLE VIII

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.

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. Effective communication of scientific and technological ideas requires practice in making written and oral presentations, fielding questions, responding to critiques, and developing replies.

GUIDING PRINCIPLE IX

A coherent science and technology/engineering program requires district-wide planning.

An effective curriculum that addresses the learning standards of this framework needs to be planned as a unitary PreK–12 enterprise. Teachers need to work across grade levels and across schools to ensure that the curriculum is a coherent whole. There needs to be agreement among teachers in different classrooms and at different levels 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 will need to plan curricula in common with their elementary and high school colleagues and district staff. To facilitate planning, districts will need to provide their staff with adequate planning time and resources.

Implementation of an effective science and technology/engineering program requires collaboration with experts, appropriate materials, support from parents and community, ongoing professional development, and quantitative and qualitative assessment.

Implementation of an effective science and technology/engineering curriculum aligned with these learning standards at every grade level is a multiyear process. The district coordinator should be involved in articulating, coordinating, and piloting a district-wide (PreK–12) science and technology/engineering curriculum. Districts may choose to pilot and systematically evaluate several different programs in multiple classrooms. Following the choice of a program, implementation may proceed one grade at a time or by introduction of a limited number of units at several grade levels each year.

School districts should select engaging, challenging, and accurate curriculum materials that are based on research on how children learn science and on how to overcome student misconceptions. To aid their selection, districts may want to consult the *Guidebook to Examine School Curricula* in the TIMSS Toolkit or Appendix VII in this framework, “Criteria for Evaluating Instructional Materials and Programs.”

Implementation also requires extensive professional development. Teachers must have the content knowledge and the pedagogical expertise to use the materials in a way that enhances student learning. A well-planned program for professional development should provide for both content learning and content-based pedagogical training. Each area of science study should be taught by teachers who are certified in that area. Because of the nature of the technology/engineering environment, it is strongly recommended that it be taught in the middle and high school by teachers who are certified in technology education, and who are therefore very familiar with the safe use of tools and machines. Science and technology/engineering coordinators for the elementary grades could help to ensure that teachers in elementary schools are supported in their efforts to help students learn science and technology/engineering.

Introduction of a new science and technology/engineering program can be more effective when families and community members are brought into the selection and planning process. 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 a new curriculum. Teachers and administrators should invite scientists, engineers, higher education faculty, representatives of local businesses, and museum personnel to help evaluate the planned curriculum and enrich it with community connections.

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, and make this information available to a broad range of participants. Teacher teams, working across grade levels, should look at student work and other forms of assessment to determine whether there is evidence for the sought-for gains in student understanding.

Science and Technology/Engineering
Learning Standards,
PreK–High School

STRAND 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 a study of earth and space, students learn about the nature and interactions of oceans and the atmosphere, 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 the 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. The learning standards at this level fall under the topics of *Earth's Materials*, *Weather*, *Sun as a Source of Heat and Light*, and *Periodic Phenomena*.

In grades 3–5, students explore properties of earth 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 fall under the topics of *Rocks and Their Properties*, *Soil*, *Weather*, *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 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.

At this level, students 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 of 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 fall under the topics of *Mapping the Earth*, *Earth's Structure*, *Heat Transfer in the Earth System*, *Earth's History*, and *The Earth in the Solar System*.

The unifying theme of 9th and 10th grade earth and space science is the interaction of the Earth's various spheres and human activities. It falls into the following categories: *Matter and Energy in the Earth System*, *Earth's Sources of Energy*, *Earth's Processes and Cycles*, and *The Origin and Evolution of the Universe*. Students continue their studies to include the universe. As they review geological, meteorological, oceanographic, and astronomical data, they learn about direct and indirect evidence and consider how these might be used to test competing theories about the origin of stars and planets, including our own solar system. Through increasingly sophisticated investigations and measurements, students also learn about various geological processes, including plate tectonics, wind formation, the flow of water through the local watershed, and changes in the earth over time.

Earth and Space Science, Grades 6–8

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES
Mapping the Earth	
<p>1. Recognize, interpret, and be able to create models of the earth’s common physical features in various mapping representations, including contour maps.</p>	<ul style="list-style-type: none"> 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	
<p>2. Describe the layers of the solid earth, including the lithosphere, the hot convecting mantle, and the dense metallic core.</p>	<ul style="list-style-type: none"> Use a Styrofoam ball and paint to construct a cross-section model of the earth.
Heat Transfer in the Earth’s System	
<p>3. Differentiate among radiation, conduction, and convection, the three mechanisms by which heat is transferred through the earth’s system.</p>	<ul style="list-style-type: none"> 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.
<p>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.</p>	<ul style="list-style-type: none"> Note the relationship between global wind patterns and ocean current patterns.
Earth’s History	
<p>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).</p>	<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.
<p>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.</p>	<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.)	
<p>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.</p>	<ul style="list-style-type: none"> • 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	
<p> 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.</p>	<ul style="list-style-type: none"> • 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.
<p>9. Describe lunar and solar eclipses, the observed moon phases, and tides. Relate them to the relative positions of the earth, moon, and sun.</p>	<ul style="list-style-type: none"> • Use globes and a light source to explain why high tides on two successive mornings are typically about 25 hours (rather than 24) apart.
<p>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).</p>	<ul style="list-style-type: none"> • 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 to you on the surface of the moon, Mars, Earth, and Jupiter.
<p> 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.</p>	
<p>12. Recognize that the universe contains many billions of galaxies, and that each galaxy contains many billions of stars.</p>	<ul style="list-style-type: none"> • Count the number of stars you can see with your 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 your answers.

Earth and Space Science, Grade 9 or 10


Learning Standards for a Full First-Year Course

1. Matter and Energy in the Earth System

Broad Concept: The earth has internal and external sources of energy. The sun is the major external source of energy while the primary sources of internal energy are generated through radioactive decay and gravitational attraction from the earth's original formation.

-  **1.1 Identify the earth's principal sources of internal and external energy, e.g., radioactive decay, gravity, solar energy.**

Broad Concept: Two fundamental energy concepts included in the earth system are gravity and electromagnetism.

-  **1.2 Describe the components of the electromagnetic spectrum and give examples of its impact on our lives.**

- 1.3 Describe the characteristics of waves (wavelength, frequency, velocity, amplitude).**


- 1.4 Describe the nature of the continuous emission and absorption spectrum that indicates the composition of stars.

Broad Concept: Global atmospheric processes are driven by energy from the sun, unequal heating between the equator and poles, the earth's rotation and revolution, and the influence of land and water. Human affairs can dramatically influence and be influenced by atmospheric phenomena.

- 1.5 Explain how the transfer of energy through radiation, conduction, and convection contributes to global atmospheric processes, e.g., storms, winds.***

- 1.6 Explain how the layers of the atmosphere affect the dispersal of incoming radiation through reflection, absorption, and reradiation.

- 1.7 Provide examples of how the unequal heating of the earth and the Coriolis Effect influence global circulation patterns, and show their impact on Massachusetts weather and climate, e.g., convection cells, trade winds, westerlies, polar easterlies, land/sea breezes, mountain/valley breezes.**

-  **1.8 Explain how the revolution of the earth and the inclination of the axis of the earth cause the earth's seasonal variations (equinoxes and solstices).***

- 1.9 Describe how the inclination of the incoming solar radiation can impact the amount of energy received by a given surface area.

- 1.10 Describe the various conditions associated with frontal boundaries and cyclonic storms (e.g., thunderstorms, winter storms [nor'easters], hurricanes, and tornadoes) and their impact on human affairs, including storm preparations.**

Boldface type indicates core standards for full-year courses. An asterisk (*) indicates core standards for integrated courses.

Earth and Space Science, Grade 9 or 10

Learning Standards for a Full First-Year Course

Broad Concept: Oceans redistribute matter and energy around the earth, through surface and deepwater currents, tides, waves, and interaction with other earth spheres.



1.11 Explain the dynamics of oceanic currents, including upwelling, density, and deep water currents, the local Labrador Current and the Gulf Stream, and their relationship to global circulation within the marine environment and climate.*

1.12 Describe the effects of longshore currents, storms, and artificial structures (e.g., jetties, sea walls) on coastal erosion in Massachusetts.

1.13 Explain what causes the tides and describe how they affect the coastal environment.

Broad Concept: Scientists use various instruments and methods to investigate the earth as a system.

1.14 Explain how scientists study the earth system through the use of a combination of ground-based observations, satellite observations, and computer models of the earth system, and why it is necessary to use all of these tools together.

2. The Earth's Sources of Energy

Broad Concept: Numerous earth resources are used to sustain human affairs. The abundance and accessibility of these resources can influence their use.



2.1 Recognize, describe, and differentiate between renewable (e.g., solar, wind, water, biomass) and nonrenewable (e.g., fossil fuels, nuclear [Ura-235]) sources of energy.

2.2 Explain the advantage and limitations of renewable sources of energy.

2.3 Explain the advantage and limitations of nonrenewable sources of energy.

2.4 Describe ways in which people have tried to control the use of renewable and nonrenewable sources of energy, e.g., scientific advances, prices.

2.5 Describe the effects on the environment of using both renewable and nonrenewable sources of energy.

2.6 Describe ways in which scientists are addressing effects on the environment of using both renewable and nonrenewable sources of energy, e.g., creation of new technologies.

3. Earth Processes and Cycles

Broad Concept: Interactions among the lithosphere, hydrosphere, and atmosphere have resulted in ongoing evolution of the earth system over geologic time.



3.1 Explain that weather is the most significant source of erosion and how both physical and chemical weathering lead to the formation of sediments and soils, affect the shape of rocks, and create specific landscapes depending on what weathering process is dominant under a specific climate.

3.2 Describe how glaciers, gravity, wind, temperature changes, waves, and rivers cause weathering and erosion. Give examples of how the effects of these processes can be seen in our local environment.*

Boldface type indicates core standards for full-year courses. An asterisk (*) indicates core standards for integrated courses.

Earth and Space Science, Grade 9 or 10

Learning Standards for a Full First-Year Course



3.3 Explain the nitrogen and carbon cycles and their roles in the improvement of soils for agriculture.

3.4 Describe the evolution of the atmosphere.

3.5 Describe how the oceans store carbon dioxide as dissolved HCO_3 and CaCO_3 precipitate.

Broad Concept: Water is continually being recycled by the hydrologic cycle through the watersheds, oceans, and the atmosphere by processes such as evaporation, condensation, precipitation, runoff, and infiltration. This life-giving cycle is continually and increasingly impacted by human affairs.



3.6 Explain how water flows into and through a watershed, e.g., aquifers, wells, porosity, permeability, water table, capillary water, runoff.*

3.7 Compare and contrast the processes of the hydrologic cycle including evaporation, condensation, precipitation, surface runoff and groundwater percolation, infiltration, and transpiration.

Broad Concept: Rocks and minerals are continually being modified within the rock cycle.



3.8 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.*

3.9 Compare the physical properties and the mineral combinations found in rocks.

3.10 Explain how the composition and arrangement of atoms determine a mineral's physical and chemical characteristics.

Broad Concept: Geologic time can be determined by analyzing rocks and fossils.



3.11 Describe the absolute and relative dating methods used to measure geologic time, e.g., index fossils, radioactive dating, law of superposition, and cross-cutting relationships.*

3.12 Describe the evolution of the solid earth in terms of the major geologic eras.

Broad Concept: The earth is a system of interacting spherical layers with each layer having distinct characteristic compositions, physical properties, and processes.

3.13 Explain how seismic data is used to reveal the interior structure of the layered earth.

3.14 Explain how seismic data is used to locate an earthquake epicenter.

3.15 Recognize the magnitude values of earthquakes as measured by the Richter Scale and give examples of relative damage that would be incurred at each magnitude.

Boldface type indicates core standards for full-year courses. An asterisk (*) indicates core standards for integrated courses.

Earth and Space Science, Grade 9 or 10

Learning Standards for a Full First-Year Course

- 3.16 Explain how the magnetic field of the earth is produced.
- 3.17 Explain how the Van Allen Belts protect the biosphere
- 3.18 Explain how paleomagnetic patterns, preserved in rocks, provide evidence of the earth's magnetic field over geologic time.

Broad Concept: Plate tectonics operating over geologic time have altered the features of land, sea, and mountains by both constructive and destructive processes.

- 3.19 Trace the development of a lithospheric plate from its growing margin at a divergent boundary (mid-ocean ridge) to its destructive margin at a convergent boundary (subduction zone). Explain the relationship between convection currents and the motion of the lithospheric plates.***



- 3.20 Relate earthquakes, volcanic activity, mountain building, and tectonic uplift to plate movements.**

- 3.21 Relate the effects of sudden seafloor movements to the generation of tsunamis.
- 3.22 Provide examples of how societies have been affected by tectonic activity (e.g., hazards from eruptions and earthquakes, bedrock type and soil conditions, building designs).

4. The Origin and Evolution of the Universe

Broad Concept: The origin of the universe, between 10 and 20 billion years ago, remains one of the greatest questions in science.

- 4.1 Explain the Big Bang Theory and discuss the evidence that supports it (background radiation, and Relativistic Doppler effect ~ red shift).**
- 4.2 Define the unit of distance called a light year.

Broad Concept: 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. These objects move in regular patterns under the influence of gravity.

- 4.3 Use the Hertzsprung-Russell Diagram to explain the life histories of stars.**
- 4.4 Compare and contrast the final three outcomes of stellar evolution based on mass (black hole, neutron star, white dwarf).

Boldface type indicates core standards for full-year courses. An asterisk (*) indicates core standards for integrated courses.

Earth and Space Science, Grade 9 or 10

Learning Standards for a Full First-Year Course

Broad Concept: Our solar system is composed of a star, planets, moons, asteroids, comets, and residual material left from the evolution of the solar system over time.

- 4.5 Compare and contrast the motions of rotation and revolution of orbiting bodies, e.g., day, year, solar/lunar eclipses. Describe the influence of gravity and inertia on these motions.**
- 4.6 Explain Kepler's Laws of Motion.
- 4.7 Compare and contrast the various instrumentation used to study deep space and the solar system, e.g., refracting telescope, reflecting telescope, radio telescope, spectrophotometer.
- 4.8 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.***

Boldface type indicates core standards for full-year courses. An asterisk (*) indicates core standards for integrated courses.

STRAND 2: 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 young children, 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. Young children learn to use their senses to observe and then describe the natural world. Noticing differences and similarities and grouping organisms based on some common features is fundamental to 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 under Content Standard C: Developing Student Understanding (www.nap.edu/readingroom/books/nse/html/6c.html).

As children move through the elementary grades, they expand the range of observations they make of the living world. In particular, children record details of the life cycles of plants and animals, and explore how organisms are adapted to their habitat. In these grades, children 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. Children are introduced to the power of empirical evidence as they design ways of exploring questions that arise from their observations. Learning standards in PreK–2 fall under the topics of *Characteristics of Living Things*, *Life Cycles*, *Evolution and Biodiversity*, *Heredity*, and *Living Things and Their Environment*. The standards for grades 3–5 fall under the topics of *Characteristics of Plants and Animals*, *Plant Structures and Functions*, *Life Cycles*, *Heredity*, *Adaptations of Living Things*, and *Energy and Living Things*.




As students enter the middle school grades, the emphasis changes from observation and description of individual organisms to the development of a more connected view of biological systems. Middle school students 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 cells of multicellular organisms can be physically very different from each other and relate that fact to the specific role that each cell has in the organisms (specialization). For example, cells of the eye or the skin or the tongue look different and do different things. Middle school students 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. As is outlined in the National Science Education Standards, students 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. Middle school students also examine the hierarchical organization of multicellular organisms and the roles and relationships that organisms occupy in an ecosystem.

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. The standards for grades 6–8 fall under the topics of *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, students study the molecular basis of life by looking at the processes occurring in cells. In particular, these students learn that the DNA molecule dictates all of our physical traits and that we inherit our parents' DNA and therefore their physical traits. They learn that genetic variation is inherited and that the unit of inheritance is the gene. It is the inherited traits that provide the variation on which natural and manipulated selection act. It is changes in the DNA over time (mutations) that lead to diversity and the appearance of new traits that can give an organism a selective advantage, allowing it to become more competitive in a given environment, survive better, or adapt to changes in the environment (basis of natural selection).

The theory of organic evolution is fundamental to understanding modern biology. It provides 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.




Life Science (Biology), Grades 6–8

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES
Classification of Organisms	
<p> 1. Classify organisms into the currently recognized kingdoms according to characteristics that they share. Be familiar with organisms from each kingdom.</p>	
Structure and Function of Cells	
<p>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.</p>	<ul style="list-style-type: none"> • Observe, describe, record, and compare a variety of unicellular organisms found in aquatic ecosystems.
<p> 3. Compare and contrast plant and animal cells, including major organelles (cell membrane, cell wall, nucleus, cytoplasm, chloroplasts, mitochondria, vacuoles).</p>	<ul style="list-style-type: none"> • Observe a range of plant and animal cells to identify the cell wall, cell membrane, chloroplasts, vacuoles, nucleus, and cytoplasm when present.
<p>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.</p>	
Systems in Living Things	
<p> 5. Describe the hierarchical organization of multicellular organisms from cells to tissues to organs to systems to organisms.</p>	
<p>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.</p>	

Life Science (Biology), Grades 6–8

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES
Reproduction and Heredity	
<p>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.</p>	
<p>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.</p>	
<p> 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).</p>	
Evolution and Biodiversity	
<p>10. Give examples of ways in which genetic variation and environmental factors are causes of evolution and the diversity of organisms.</p>	
<p>11. Recognize that evidence drawn from geology, fossils, and comparative anatomy provide the basis of the theory of evolution.</p>	<ul style="list-style-type: none"> • 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.
<p>12. Relate the extinction of species to a mismatch of adaptation and the environment.</p>	<ul style="list-style-type: none"> • 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	
<p>13. Give examples of ways in which organisms interact and have different functions within an ecosystem that enable the ecosystem to survive.</p>	<ul style="list-style-type: none"> • 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	
<p> 14. Explain the roles and relationships among producers, consumers, and decomposers in the process of energy transfer in a food web.</p>	<ul style="list-style-type: none"> 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.
<p> 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.</p>	<ul style="list-style-type: none"> 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.
<p>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.</p>	<ul style="list-style-type: none"> Test for sugars and starch in plant leaves.
Changes in Ecosystems Over Time	
<p> 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.</p>	<ul style="list-style-type: none"> 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.
<p>18. Recognize that biological evolution accounts for the diversity of species developed through gradual processes over many generations.</p>	

Biology, Grade 9 or 10

Learning Standards for a Full First-Year Course



1. The Chemistry of Life

Broad Concept: Living things are made of atoms bonded together to form organic molecules.

- 1.1 **Explain the significance of carbon in organic molecules.**
- 1.2 **Recognize the six most common elements in organic molecules (C, H, N, O, P, S).**
-  1.3 **Describe the composition and functions of the four major categories of organic molecules (carbohydrates, lipids, proteins, and nucleic acids).***
- 1.4 Describe how dehydration synthesis and hydrolysis relate to organic molecules.
- 1.5 **Explain the role of enzymes in biochemical reactions.**

2. Structure and Function of Cells

Broad Concept: All living things are composed of cells. Life processes in a cell are based on molecular interactions.

- 2.1 **Relate cell parts/organelles to their functions.***
-  2.2 **Differentiate between prokaryotic cells and eukaryotic cells, in terms of their general structures and degrees of complexity.***
- 2.3 **Distinguish between plant and animal cells.***
- 2.4 Describe how cells function in a narrow range of physical conditions, such as temperature and pH, to perform life functions that help to maintain homeostasis.
- 2.5 **Explain the role of cell membranes as a highly selective barrier (diffusion, osmosis, and active transport).***
- 2.6 **Identify the reactants and products in the general reaction of photosynthesis. Describe the use of isotopes in this identification.**
- 2.7 **Provide evidence that the organic compounds produced by plants are the primary source of energy and nutrients for most living things.***
- 2.8 **Identify how cellular respiration is important for the production of ATP.**
- 2.9 **Explain the interrelated nature of photosynthesis and cellular respiration.***
-  2.10 **Describe and compare the processes of mitosis and meiosis, and their role in the cell cycle.***

Boldface type indicates core standards for full-year courses. An asterisk (*) indicates core standards for integrated courses.

Biology, Grade 9 or 10

Learning Standards for a Full First-Year Course

3. Genetics

Broad Concept: Genes are a set of instructions encoded in the DNA sequence of each organism that specify the sequence of amino acids in proteins characteristic of that organism.

3.1 Describe the structure and function of DNA, and distinguish among replication, transcription, and translation.*



3.2 Describe the processes of replication, transcription, and translation and how they relate to each other in molecular biology.

3.3 Describe the general pathway by which ribosomes synthesize proteins by using tRNAs to translate genetic information encoded in mRNAs.

3.4 Explain how mutations in the DNA sequence of a gene may be silent or result in phenotypic change in an organism and in its offspring.

3.5 Differentiate between dominant, recessive, codominant, polygenic, and sex-linked traits.

3.6 State Mendel's laws of segregation and independent assortment.

3.7 Use a Punnett Square to determine the genotype and phenotype of monohybrid crosses.*

3.8 Explain how zygotes are produced in the fertilization process.

3.9 Recognize that while viruses lack cellular structure, they have the genetic material to invade living cells.

4. Human Anatomy and Physiology

Broad Concept: There is a relationship between structure and function in organ systems of humans.

4.1 Explain how major organ systems in humans (e.g., kidney, muscle, lung) have functional units (e.g., nephron, sarcome, alveoli) with specific anatomy that perform the function of that organ system.

4.2 Describe how the function of individual systems within humans are integrated to maintain a homeostatic balance in the body.

5. Evolution and Biodiversity

Broad Concept: Evolution and biodiversity are the result of genetic changes that occur in constantly changing environments.

5.1 Explain how the fossil record, comparative anatomy, and other evidence support the theory of evolution.

5.2 Illustrate how genetic variation is preserved or eliminated from a population through Darwinian natural selection (evolution) resulting in biodiversity.

Boldface type indicates core standards for full-year courses. An asterisk (*) indicates core standards for integrated courses.

Biology, Grade 9 or 10

Learning Standards for a Full First-Year Course

- 5.3 Describe how the taxonomic system classifies living things into domains (eubacteria, archaeobacteria, and eukaryotes) and kingdoms (animals, plants, fungi, etc.).*** [Note: there is an ongoing scientific debate about the number of kingdoms and which organisms should be included in each. The following websites provide more information: Brave New Biosphere whyfiles.org/022critters/phylogeny.html, and The Tree of Life Project Root Page phylogeny.arizona.edu/tree/life.html.]

6. Ecology

Broad Concept: Ecology is the interaction between living organisms and their environment.



- 6.1 Explain how biotic and abiotic factors cycle in an ecosystem (water, carbon, oxygen, and nitrogen).***
- 6.2 Use a food web to identify and distinguish producers, consumers, and decomposers, and explain the transfer of energy through trophic levels.***
- 6.3 Identify the factors in an ecosystem that influence fluctuations in population size.
- 6.4 Analyze changes in an ecosystem resulting from natural causes, changes in climate, human activity, or introduction of non-native species.
- 6.5 Explain how symbiotic behavior produces interactions within ecosystems.

Boldface type indicates core standards for full-year courses. An asterisk (*) indicates core standards for integrated courses.

STRAND 3: PHYSICAL SCIENCES (CHEMISTRY AND PHYSICS)

The physical sciences (physics and chemistry) 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.

The physical science learning standards for PreK–2 fall under the topics of *Observable Properties of Objects, States of Matter, and Position and Motion of Objects*. Young children’s curiosity is engaged when they observe physical processes and sort objects by different criteria. During these activities, children learn basic concepts about how things are alike or different. As they push, pull, and transform objects by acting upon them, children 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.

The standards for grades 3–5 fall under the topics of *Properties of Objects and Materials, States of Matter, and Forms of Energy* (including electrical, magnetic, sound, and light). Students’ growth in their understanding of ordinary things allows them to make the intellectual connections necessary for understanding 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.

The standards for grades 6–8 fall under the topics of *Properties of Matter, Elements, Compounds and Mixtures, Motion of Objects, Forms of Energy, and Heat Energy*. While students at the middle school level may be better able to manage and represent ideas through language and mathematics, they 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 are able to understand relationships and can graph one measurement in relation to another, such as temperature change over time. Students may collect data by using microcomputer- or calculator-based laboratories (MBL or CBL), and learn to make sense immediately of graphical and other abstract representations essential to scientific understanding.

The high school standards for physics include *Motion, Forces, Energy, Waves, and Electromagnetism*. At the end of their study based on these standards, students can understand the evidence that underlies more complex concepts of physics, including forces and vectors, and transformations of energy. Graphical representations and the gradual introduction of functions introduce students to well-defined laws and principles of physics.

The high school chemistry standards for a full-year study include *Properties of Matter, Atomic Structure and Bonding, Chemical Reactions and Stoichiometry, Solutions, Acids and Bases, and Equilibrium and Kinetics*. Because chemistry is central to our understanding of many other sciences, chemistry instruction should include links to actual applications to enable students to relate chemistry to their everyday lives and current engineering/technology. At the end of their study, students are capable of using sophisticated models and rigorous mathematical computations to make formal statements of principles of chemistry and understand their implications. They are able to apply their understanding in another science course, in a higher level of science or engineering/technology learning, or in the experiences they encounter.

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

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES
Properties of Matter	
<p>1. Differentiate between weight and mass, recognizing that weight is the amount of gravitational pull on an object.</p>	<ul style="list-style-type: none"> Explain how to determine the weight of a dense object in air and in water. Next carry out your plan. Explain how the results you obtain are related to the different definitions of mass and weight.
<p>2. Differentiate between volume and mass. Define density.</p>	
<p>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.</p>	<ul style="list-style-type: none"> 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 your procedures and how they explain any observed differences between your calculated volumes and your measured volumes.
<p>4. Explain and give examples of how mass is conserved in a closed system.</p>	<ul style="list-style-type: none"> Melt, dissolve, and precipitate various substances to observe examples of the conservation of mass.
Elements, Compounds, and Mixtures	
<p>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.</p>	<ul style="list-style-type: none"> 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 chemical reactions you are modeling.
<p>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).</p>	<ul style="list-style-type: none"> Use atomic models (or Lego blocks, assigning colors to various atoms) to build molecules of water, sodium chloride, carbon dioxide, ammonia, etc.

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

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES
Elements, Compounds, and Mixtures (cont.)	
<p>7. Give basic examples of elements and compounds.</p>	<ul style="list-style-type: none"> Heat sugar in a crucible with an inverted funnel over it. Observe carbon residue and water vapor in the funnel as evidence of the break-down 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.
<p>8. Differentiate between mixtures and pure substances.</p>	
<p>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.</p>	
<p>10. Differentiate between physical changes and chemical changes.</p>	<ul style="list-style-type: none"> 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	
<p>11. Explain and give examples of how the motion of an object can be described by its position, direction of motion, and speed.</p>	
<p>12. Graph and interpret distance vs. time graphs for constant speed.</p>	
Forms of Energy	
<p>13. Differentiate between potential and kinetic energy. Identify situations where kinetic energy is transformed into potential energy and vice versa.</p>	

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

LEARNING STANDARD	IDEAS FOR DEVELOPING INVESTIGATIONS AND LEARNING EXPERIENCES
Heat Energy	
<p>14. Recognize that heat is a form of energy and that temperature change results from adding or taking away heat from a system.</p>	
<p>15. Explain the effect of heat on particle motion through a description of what happens to particles during a change in phase.</p>	
<p>16. Give examples of how heat moves in predictable ways, moving from warmer objects to cooler ones until they reach equilibrium.</p>	<ul style="list-style-type: none"> 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. Include direction of heat flow and why it stops.

Chemistry, Grade 10 or 11

Learning Standards for a Full First-Year Course

1. Properties of Matter

Broad Concept: Physical and chemical properties can be used to classify and describe matter.

1.1 Identify and explain some of the physical properties that are used to classify matter, e.g., density, melting point, and boiling point.*



1.2 Explain the difference between mixtures and pure substances.*

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

1.4 Distinguish between chemical and physical changes.

2. Atomic Structure

Broad Concept: An atom is a discrete unit. The atomic model can help us to understand the interaction of elements and compounds observed on a macroscopic scale.



2.1 Trace the development of atomic theory and the structure of the atom from the ancient Greeks to the present (Dalton, Thompson, Rutherford, Bohr, and modern theory).

2.2 Interpret Dalton's atomic theory in terms of the Laws of Conservation of Mass, Constant Composition, and Multiple Proportions.



2.3 Identify the major components of the nuclear atom (protons, neutrons, and electrons) and explain how they interact.*

2.4 Understand that matter has properties of both particles and waves.

2.5 Using Bohr's model of the atom interpret changes (emission/absorption) in electron energies in the hydrogen atom corresponding to emission transitions between quantum levels.



2.6 Describe the electromagnetic spectrum in terms of wavelength and energy; identify regions of the electromagnetic spectrum.

2.7 Write the electron configurations for elements in the first three rows of the periodic table.

2.8 Describe alpha, beta, and gamma particles; discuss the properties of alpha, beta, and gamma radiation; and write balanced nuclear reactions.

2.9 Compare nuclear fission and nuclear fusion and mass defect.*

2.10 Describe the process of radioactive decay as the spontaneous breakdown of certain unstable elements (radioactive) into new elements (radioactive or not) through the spontaneous emission by the nucleus of alpha or beta particles. Explain the difference between stable and unstable isotopes.

2.11 Explain the concept of half-life of a radioactive element, e.g., explain why the half-life of C14 has made carbon dating a powerful tool in determining the age of very old objects.

Boldface type indicates core standards for full-year courses. An asterisk (*) indicates core standards for integrated courses.

Chemistry, Grade 10 or 11

Learning Standards for a Full First-Year Course

3. Periodicity

Broad Concept: Periodicity of physical and chemical properties relates to atomic structure and led to the development of the periodic table. The periodic table displays the elements in order of increasing atomic number.

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

4. Chemical Bonding

Broad Concept: Atoms form bonds by the interactions of their valence electrons.



4.1 Explain how atoms combine to form compounds through both ionic and covalent bonding.*

4.2 Draw Lewis dot structures for simple molecules.

4.3 Relate electronegativity and ionization energy to the type of bonding an element is likely to undergo.

4.4 Predict the geometry of simple molecules and their polarity (valence shell electron pair repulsion).

4.5 Identify the types of intermolecular forces present based on molecular geometry and polarity.

4.6 Predict chemical formulas based on the number of valence electrons.

4.7 Name and write the chemical formulas for simple ionic and molecular compounds, including those that contain common polyatomic ions.

5. Chemical Reactions and Stoichiometry

Broad Concept: The conservation of atoms in chemical reactions leads to the ability to calculate the mass of products and reactants.

5.1 Balance chemical equations by applying the law of conservation of mass.*



5.2 Recognize synthesis, decomposition, single displacement, double displacement, and neutralization reactions.

5.3 Understand the mole concept in terms of number of particles, mass, and gaseous volume.

Boldface type indicates core standards for full-year courses. An asterisk (*) indicates core standards for integrated courses.

Chemistry, Grade 10 or 11

Learning Standards for a Full First-Year Course

- 5.4 Determine molar mass, percent compositions, empirical formulas, and molecular formulas.
- 5.5 Calculate mass-mass, mass-volume, volume-volume, and limiting reactant problems for chemical reactions.
- 5.6 Calculate percent yield in a chemical reaction.

6. Gases and Kinetic Molecular Theory

Broad Concept: The behavior of gases can be explained by the Kinetic Molecular Theory.



6.1 Using the kinetic molecular theory, explain the relationship between pressure and volume (Boyle's law), volume and temperature (Charles' law), and the number of particles in a gas sample (Avogadro's hypothesis).

6.2 Explain the relationship between temperature and average kinetic energy.

6.3 Perform calculations using the ideal gas law.

6.4 Describe the conditions under which a real gas deviates from ideal behavior.

6.5 Interpret Dalton's empirical Law of Partial Pressures and use it to calculate partial pressures and total pressures.

6.6 Use the combined gas law to determine changes in pressure, volume, or temperature.

7. Solutions

Broad Concept: Solids, liquids, and gases dissolve to form solutions.

7.1 Describe the process by which solutes dissolve in solvents.*



7.2 Identify and explain the factors that affect the rate of dissolving (i.e., temperature, concentration, and mixing).*

7.3 Describe the dynamic equilibrium that occurs in saturated solutions.

7.4 Calculate concentration in terms of molarity, molality, and percent by mass.

7.5 Use a solubility curve to determine saturation values at different temperatures.

7.6 Calculate the freezing point depression and boiling point elevation of a solution.

7.7 Write net ionic equations for precipitation reactions in aqueous solutions.

8. Acids and Bases

Broad Concept: Acids and bases are important in numerous chemical processes that occur around us, from industrial processes to biological ones, from the laboratory to the environment.

8.1 Define Arrhenius' theory of acids and bases in terms of the presence of hydronium and hydroxide ions, and Bronsted's theory of acids and bases in terms of proton donor and acceptor, and relate their concentrations to the pH scale. *

Boldface type indicates core standards for full-year courses. An asterisk (*) indicates core standards for integrated courses.


Chemistry, Grade 10 or 11

Learning Standards for a Full First-Year Course

- 8.2 Compare and contrast the nature, behavior, concentration and strength of acids and bases.
 - a. Acid-base neutralization
 - b. Degree of dissociation or ionization
 - c. Electrical conductivity
- 8.3 Identify a buffer and explain how it works.
- 8.4 Explain how indicators are used in titrations and how they are selected.
- 8.5 Describe an acid-base titration. Identify when the equivalence point is reached and its significance.
- 8.6 Calculate the pH or pOH of aqueous solutions using the hydronium or hydroxide ion concentration.

9. Equilibrium and Kinetics

Broad Concept: Chemical equilibrium is a dynamic process that is significant in many systems (biological, ecological and geological). Chemical reactions occur at different rates.

- 9.1 Write the equilibrium expression and calculate the equilibrium constant for a reaction.
- 9.2 Predict the shift in equilibrium when the system is subjected to a stress (LeChatelier's principle).
-  **9.3 Identify the factors that affect the rate of a chemical reaction (temperature, concentration) and the factors that can cause a shift in equilibrium (concentration, pressure, volume, temperature).**
- 9.4 Explain rates of reaction in terms of collision frequency, energy of collisions, and orientation of colliding molecules.
- 9.5 Define the role of activation energy in a chemical reaction.

10. Thermochemistry (Enthalpy)

Broad Concept: The driving forces of chemical reactions are energy and entropy. This has important implications for many applications (synthesis of new compounds, meteorology, and industrial engineering).

- 10.1 Interpret the law of conservation of energy.
- 10.2 Explain the relationship between energy transfer and disorder in the universe.
- 10.3 Analyze the energy changes involved in physical and chemical processes using calorimetry.
- 10.4 Apply Hess's law to determine the heat of reaction.

Boldface type indicates core standards for full-year courses. An asterisk (*) indicates core standards for integrated courses.

Chemistry, Grade 10 or 11

Learning Standards for a Full First-Year Course

11. Oxidation-Reduction and Electrochemistry

Broad Concept: Oxidation-reduction reactions occur by electron transfer and constitute a major class of chemical reactions. Examples of redox reactions occur everywhere; their consequences are experienced daily.

- 11.1 Describe the chemical processes known as oxidation and reduction.
- 11.2 Assign oxidation numbers.
- 11.3 Balance oxidation-reduction equations by using half-reactions.
- 11.4 Identify the components, and describe the processes that occur in an electrochemical cell.
- 11.5 Explain how a typical battery, such as a lead storage battery or a dry cell, works.
- 11.6 Compare and contrast voltaic and electrolytic cells and their uses.
- 11.7 Calculate the net voltage of a cell given a table of standard reduction potentials.


Boldface type indicates core standards for full-year courses. An asterisk (*) indicates core standards for integrated courses.

Physics, Grade 9 or 10

Learning Standards for a Full First-Year Course


1. Motion and Forces

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

- 1.1 **Distinguish between vector quantities (velocity, acceleration, and force) and scalar quantities (speed and mass).**
- 1.2 Illustrate how to represent vectors graphically and be able to add them graphically.
- 1.3 **Distinguish between, and solve problems involving, velocity, speed, and constant acceleration.**
- 1.4 **Create and interpret graphs of motion (position vs. time, speed vs. time, velocity vs. time, constant acceleration vs. time).**
- 1.5 **Explain the relationship between mass and inertia.***
- 1.6 **Interpret and apply Newton's first law of motion.***
- 1.7 **Interpret and apply Newton's second law of motion to show how an object's motion will change only when a net force is applied.***
-  1.8 **Use a free body force diagram with only co-linear forces to show forces acting on an object, and determine the net force on it.**
- 1.9 Qualitatively distinguish between static and kinetic friction, what they depend on and their effects on the motion of objects.
- 1.10 **Interpret and apply Newton's third law of motion.**
- 1.11 **Understand conceptually Newton's law of universal gravitation. ***
- 1.12 Identify appropriate standard international units of measurement for force, mass, distance, speed, acceleration, and time, and explain how they are measured.

2. Conservation of Energy and Momentum

Broad Concept: The laws of conservation of energy and momentum provide alternate approaches to predict and describe the movement of objects.

- 2.1 **Interpret and provide examples that illustrate the law of conservation of energy. ***
- 2.2 **Provide examples of how energy can be transformed from kinetic to potential and vice versa.**
- 2.3 Apply quantitatively the law of conservation of mechanical energy to simple systems.
- 2.4 **Describe the relationship among energy, work, and power both conceptually and quantitatively.**
-  2.5 **Interpret the law of conservation of momentum and provide examples that illustrate it. Calculate the momentum of an object.**
- 2.6 Identify appropriate standard international units of measurement for energy, work, power, and momentum.

Boldface type indicates core standards for full-year courses. An asterisk (*) indicates core standards for integrated courses.

Physics, Grade 9 or 10

Learning Standards for a Full First-Year Course

3. Heat and Heat Transfer

Broad Concept: Heat is energy that is transferred between bodies that are at different temperatures by the processes of convection, conduction, and/or radiation.

- 3.1 Relate thermal energy to molecular motion.***
- 3.2 Differentiate between specific heat and heat capacity.
- 3.3 Explain the relationship among temperature change in a substance for a given amount of heat transferred, the amount (mass) of the substance, and the specific heat of the substance.**
- 3.4 Recognize that matter exists in four phases, and explain what happens during a phase change.

4. Waves

Broad Concept: Waves carry energy from place to place without the transfer of matter.

- 4.1 Differentiate between wave motion (simple harmonic nonlinear motion) and the motion of objects (nonharmonic).***
- 4.2 Recognize the measurable properties of waves (e.g., velocity, frequency, wavelength) and explain the relationships among them. ***
- 4.3 Distinguish between transverse and longitudinal waves.**
- 4.4 Distinguish between mechanical and electromagnetic waves. ***
- 4.5 Interpret and be able to apply the laws of reflection and refraction (qualitatively) to all waves.
- 4.6 Recognize the effects of polarization, wave interaction, and the Doppler effect.
- 4.7 Explain, graph, and interpret graphs of constructive and destructive interference of waves.
- 4.8 Explain the relationship between the speed of a wave (e.g., sound) and the medium it travels through.
- 4.9 Recognize the characteristics of a standing wave and explain the conditions under which two waves on a string or in a pipe can interfere to produce a standing wave.

5. Electromagnetism

Broad Concept: Stationary and moving charge particles result in the phenomenon known as electricity and magnetism.

- 5.1 Recognize the characteristics of static charge, and explain how a static charge is generated.**
- 5.2 Interpret and apply Coulomb's law.

Boldface type indicates core standards for full-year courses. An asterisk (*) indicates core standards for integrated courses.

Physics, Grade 9 or 10

Learning Standards for a Full First-Year Course

5.3 Explain the difference in concept between electric forces and electric fields.

5.4 Develop a qualitative and quantitative understanding of current, voltage, resistance, and the connection between them.



5.5 Identify appropriate units of measurement for current, voltage, and resistance, and explain how they are measured.

5.6 Analyze circuits (find the current at any point and the potential difference between any two points in the circuit) using Kirchoff's and Ohm's laws.

6. Electromagnetic Radiation

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



6.1 Describe the electromagnetic spectrum in terms of wavelength and energy, and be able to identify specific regions such as visible light.*

6.2 Explain how the various wavelengths in the electromagnetic spectrum have many useful applications such as radio, television, microwave appliances, and cellular telephones.

6.3 Calculate the frequency and energy of an electromagnetic wave from the wavelength.

6.4 Recognize and explain the ways in which the direction of visible light can be changed.

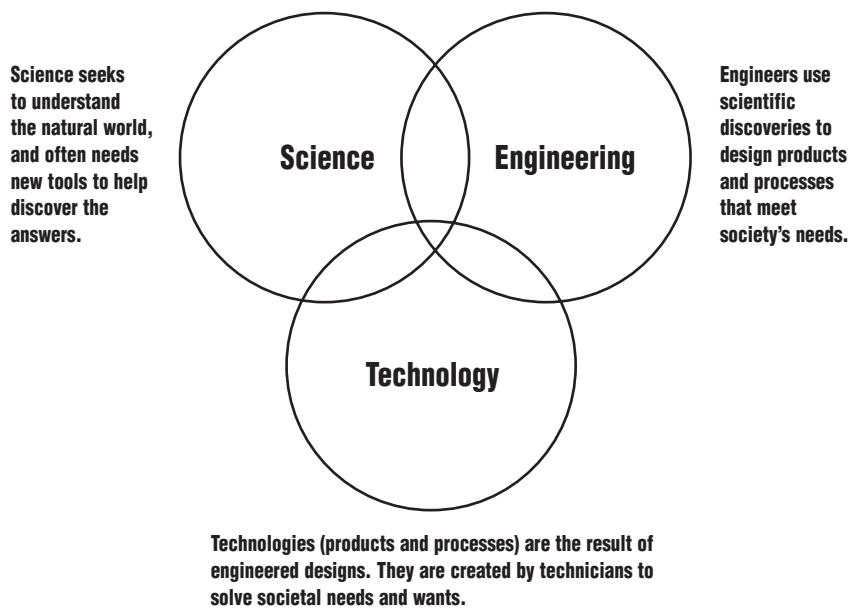
Boldface type indicates core standards for full-year courses. An asterisk (*) indicates core standards for integrated courses.

STRAND 4 : TECHNOLOGY / ENGINEERING

Science tries to understand the natural world. Based on the knowledge that scientists develop, the goal of engineering is to solve practical problems through the development or use of technologies. For example, the planning, designing, and construction of the Central Artery Tunnel project in Boston (commonly referred to as the “Big Dig”) is a complex and technologically challenging project that draws on knowledge of earth science, physics, and construction and transportation technologies.

Technology/engineering works in conjunction with science to expand our capacity to understand the world. For example, scientists and engineers apply scientific knowledge of light to develop lasers and 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 Relationship Among Science, Engineering, and Technology



Although the term technology is often used by itself to describe the educational application of computers in a classroom, instructional technology is a subset of the much broader field of technology. While important, computers and instructional tools that use computers are only a few of the many technological innovations in use today.

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 children's toys; and systems that create special effects in movies. Each of these came about as the result

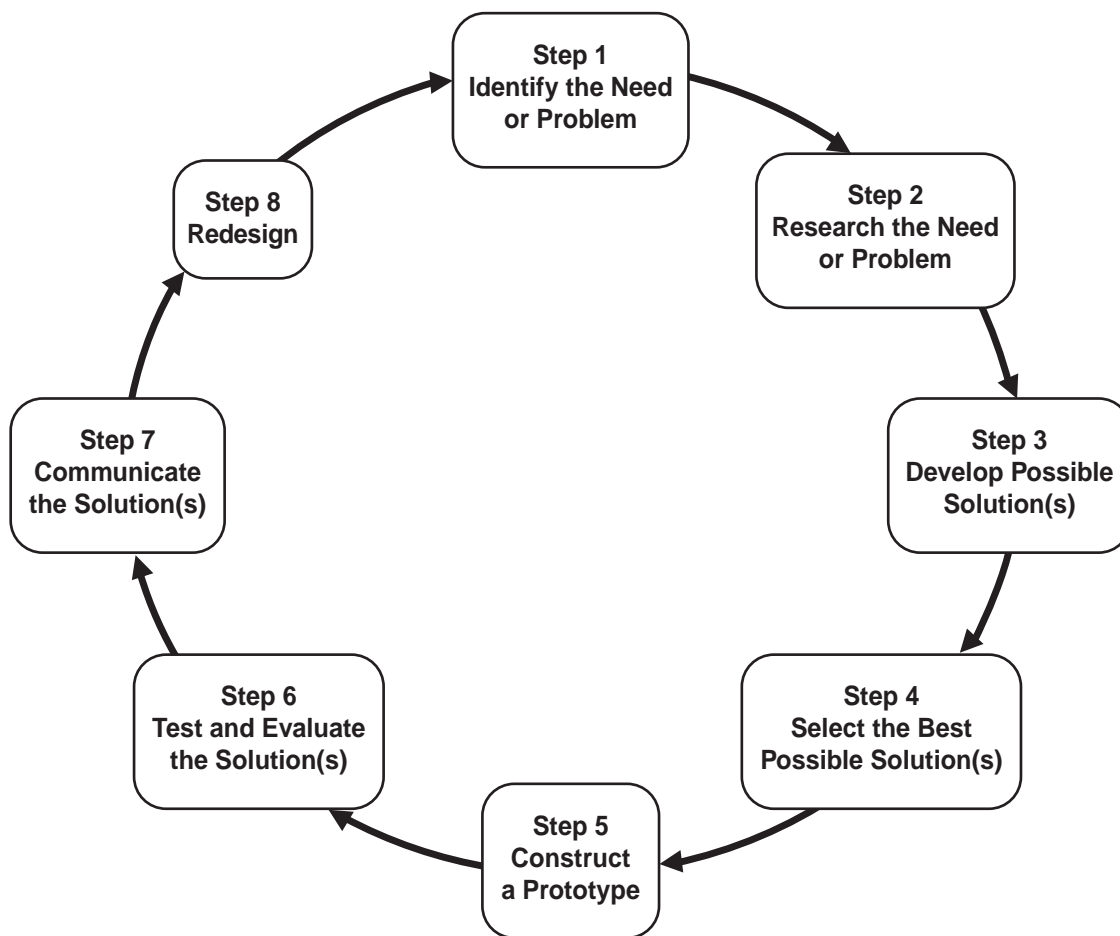
of recognizing a need or problem and creating a technological solution. Figure 1 on page 73 shows the steps of the engineering design process. Beginning in the early grades and continuing through high school, students carry out this design process in ever more sophisticated ways. As they gain more experience and knowledge, they are able to draw on other disciplines, especially mathematics and science, to understand and solve problems.

Students are experienced technology users before they enter school. 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 use of tools and materials that underlie engineering solutions, they 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 manmade materials and their possible uses and identify the use of basic tools and materials, e.g., glue, scissors, tape, ruler, paper, toothpicks, straws, and spools. In addition, students at this level learn to identify tools and simple machines used for a specific purpose (e.g., ramp, wheel, pulley, lever) and describe how human beings use parts of the body as tools.

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 a specific property 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, learn different ways that the problem can be represented, and work with a variety of materials and tools to create a product or system to address it.

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 skills in the safe 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 these grades and extending through grade 10, the topics of power and energy are incorporated into the study of most areas of technology. Students integrate knowledge they acquired in their mathematics and science curricula to understand the links to 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.

Figure 1
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 solutions
 - Explore other options via the internet, library, interviews, etc.
3. Develop possible solution(s)
 - Brainstorm possible solutions
 - Draw on mathematics and science
 - Articulate the possible solutions in two and three dimensions
 - Refine the possible solutions
4. Select the best possible solution(s)
 - Determine which solution(s) best meet(s) the original requirements
5. Construct 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 needs of the initial problem, opportunity, or need
 - Discuss societal impact and tradeoffs of the solution(s)
8. Redesign
 - Overhaul the solution(s) based on information gathered during the tests and presentation

Students in grades 9 and 10 learn to apply scientific and mathematical knowledge in a full-year, comprehensive technology/engineering course. The topics addressed include engineering design; construction technologies; power and energy technologies in fluid, thermal, and electrical systems; communication technologies; and manufacturing technologies. Students engage in experiences that enhance their skills in designing, building, and testing prototypes. The culmination of this level of design experience is also the development and delivery of an engineering presentation.

Technology/engineering curricula in grades 11 and 12 follow the approaches used for the previous two grades but expand in a variety of areas based on available school expertise and student interest. Students may explore advanced technology/engineering curricula such as automation and robotics, multimedia, architecture and planning, biotechnology, and computer information systems. They may continue building on their background in engineering design by working on inventions. Course offerings in the high school grades should engage students who are interested in:

- expanding their studies in the area of engineering and technology because they are interested in a college-level engineering program,
- pursuing career pathways in relevant technology fields, or
- learning about certain areas of technology/engineering to expand their general educational background, but who will not necessarily follow a technical career.

All areas of study should be taught by teachers who are certified in that discipline. Because of the hands-on, active nature of the technology/engineering environment, it is strongly recommended that it be taught in the middle and high school by teachers who are certified in technology education, and who are very familiar with the safe use of tools and machines.

Technology/Engineering, Grades PreK–8

Please note: Suggested extensions to learning in technology/engineering for grades PreK–5 are listed with the science learning standards. See pages 21–26 (earth and space science), 39–44 (life science), and 55–59 (physical sciences).

Grades PreK–2

1. Materials and Tools

Broad 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

Broad 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.

Grades 3–5

1. Materials and Tools

Broad 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, i.e., weight, strength, hardness, and flexibility.

Technology/Engineering, Grades PreK–8

- 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

Broad 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.

Grades 6–8

Please note: For grades 6–high school, there are suggested learning activities after each set of learning standards. The numbers in parentheses after each activity refer to the related technology/engineering learning standard(s).

1. Materials, Tools, and Machines

Broad Concept: Appropriate materials, tools, and machines enable us to solve problems, invent, and construct.

- 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., weight, strength, hardness, and flexibility).
- 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.
- 1.3 Identify and explain the safe and proper use of measuring tools, hand tools, and machines (e.g., band saw, drill press, sanders, hammer, screwdriver, pliers, tape measure, screws, nails, and other mechanical fasteners) needed to construct a prototype of an engineering design.

Suggested Learning Activities

- Conduct tests for weight, strength, hardness, and flexibility of various materials, e.g., wood, paper, plastic, ceramics, metals. (1.1)

Technology/Engineering, Grades PreK–8

- Design and build a catapult that will toss a marshmallow the farthest. (1.1, 1.2, 1.3)
- Use a variety of hand tools and machines to change materials into new forms through forming, separating, and combining processes, and processes that cause internal change to occur. (1.2)

2. Engineering Design

Broad Concept: Engineering design is an iterative process involving modeling and optimizing for developing technological solutions to problems within given constraints.

- 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.
- 2.2 Demonstrate methods of representing solutions to a design problem, e.g., sketches, orthographic projections, multiview drawings.
- 2.3 Describe and explain the purpose of a given prototype.
- 2.4 Identify appropriate materials, tools, and machines needed to construct a prototype of a given engineering design.
- 2.5 Explain how such design features as size, shape, weight, function, and cost limitations would affect the construction of a given prototype.
- 2.6 Identify the five elements of a universal systems model: goal, inputs, processes, outputs, and feedback.

Suggested Learning Activities

- 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, exhibiting a degree of craftsmanship. (2.2)

3. Communication Technologies

Broad Concept: 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).

Technology/Engineering, Grades PreK–8

- 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

Broad Concept: 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

Broad Concept: 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.
- 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).
- 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.

Suggested Learning Activities

- Design and construct a bridge following specified design criteria, e.g., size, materials used. Test the design for durability and structural stability. (5.3)

6. Transportation Technologies

Broad Concept: 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 each of the following: land, air, water, and space.

Technology/Engineering, Grades PreK–8

- 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.

Suggested Learning Activities

- 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 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, the students draw a design of a future transportation mode (car, bus, train, plane, etc.). The students present their vehicle design to the class, including a discussion of the subsystems used. (6.1, 6.3)

7. Bioengineering Technologies

Broad Concept: Bioengineering technologies explore the production of mechanical devices, products, biological substances, and organisms to improve health and/or contribute improvement 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.
- 7.2 Describe and explain adaptive and assistive bioengineered products, e.g., food, bio-fuels, irradiation, integrated pest management.

Suggested Learning Activities

- Brainstorm and evaluate alternative ideas for an adaptive device that will make life easier for a person with a disability, such as a device to pick up objects from the floor. (7.1)

Local Wonders

Adapted from the Building Big Activity Guide, pp. 36–37

Technology/Engineering, Grades 6–8

Your community may not have an Eiffel Tower or a Hoover Dam, but 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, take a bus tour around town for ideas, or collect some photographs for discussion.

After building newspaper towers and talking about structures and foundations, fifth and 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. The children brainstormed questions about their local wonder. Those with an engineering focus included: When was it built? How long did the construction take? Who built it? 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: Why was it built? What did the area look like before it was built?

Next, the students investigated their local wonder with some hands-on activities that explore basic engineering principles such as forces, compression, tension, shape, and torsion. They toured the structure, 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 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 can use the following method to estimate the size of a large structure. First, measure a friend's height. Have your friend stand next to the structure, while you stand a distance away (across the street, for instance). Close one eye and use your fingers to "stack" your friend's height until you reach the top of the structure. Multiply the number of times you stacked your friend by his/her height to find the total estimated height of the structure.

The outline of the final report may look like this:

- I. Name of group submitting report
- II. Name and description of structure (identify the type of structure, e.g., bridge, skyscraper, and describe and explain its parts)
- III. Location
- IV. Approximate date structure was completed
- V. Approximate size
- 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

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 groups' completed investigations with the students at the beginning of the project. Discuss and develop criteria for effective write-ups, 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 find. The teacher should read the journals to monitor students' progress and level 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 the local wonder they just studied. How are they alike? Different? Compare the materials, design, and purpose of these structures.

Note: The applicable standards may vary depending upon the type of structure selected.

Engineering Design Learning Standards

- 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

- 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 (e.g., arch, beam, and suspension) and their appropriate uses (e.g., 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 loads and structural shapes on bridges.

Technology/Engineering, Grade 9 or 10

Learning Standards for a Full First-Year Course

1. Engineering Design

Broad Concept: Engineering design involves practical problem solving, research, development, and invention and requires designing, drawing, building, testing, and redesigning.

- 1.1 Identify and explain the steps of the engineering design process, i.e., identify the 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.**
- 1.2 Demonstrate knowledge of pictorial and multi-view drawings (e.g., orthographic projection, isometric, oblique, perspective) using proper techniques.**
- 1.3 Demonstrate the use of drafting techniques with paper and pencil or computer-aided design (CAD) systems when available.**
- 1.4 Apply scale and proportion to drawings, e.g., $1/4'' = 1'0''$.**
- 1.5 Interpret plans, diagrams, and working drawings in the construction of a prototype.**

Suggested Learning Activities

- 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 resources/internet 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)
- Create drawings that include scale and dimension. (1.2, 1.3)

2. Construction Technologies

Broad Concept: Various materials, processes, and systems are used to build structures.

- 2.1 Distinguish among tension, compression, shear, and torsion, and explain how they relate to the selection of materials in structures.**

Boldface type indicates core standards for full-year courses.

Technology/Engineering, Grade 9 or 10

Learning Standards for a Full First-Year Course

- 2.2 Identify and explain the purposes of common tools and measurement devices used in construction, e.g., spirit level, transit, framing square, plumb bob, spring scale, tape measure, strain gauge, venturi meter, pitot tube.
- 2.3 Describe how structures are constructed using a variety of processes and procedures, e.g., welds, bolts, and rivets are used to assemble metal framing materials.
- 2.4 Identify and explain the engineering properties of materials used in structures, e.g., elasticity, plasticity, thermal conductivity, density.**
- 2.5 Differentiate the factors that affect the design and building of structures, such as zoning laws, building codes, and professional standards.
- 2.6 Calculate quantitatively the resultant forces for live loads and dead loads.**

Suggested Learning Activities

- 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, 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 such as density, strength, thermal conductivity, specific heat, and 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, 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

Broad Concept: Fluid systems are made up of liquids or gases and allow force to be transferred from one location to another. They also provide water, gas, and oil, and remove waste. They can be moving or stationary and have associated pressures and velocities.

- 3.1 Differentiate between open (e.g., irrigation, forced hot air system) and closed (e.g., forced hot water system, hydroponics) fluid systems and their components such as valves, controlling devices, and metering devices.
- 3.2 Identify and explain sources of resistance (e.g., 45° elbow, 90° elbow, type of pipes, changes in diameter) for water moving through a pipe.
- 3.3 Explain Bernoulli's Principle and its effect on practical applications, i.e., airfoil design, spoiler design, carburetor.**

Boldface type indicates core standards for full-year courses.

Technology/Engineering, Grade 9 or 10

Learning Standards for a Full First-Year Course

- 3.4 Differentiate between hydraulic and pneumatic systems and provide examples of appropriate applications of each as they relate to manufacturing and transportation systems.**
- 3.5 Explain the relationship between velocity and cross-sectional areas in the movement of a fluid.
- 3.6 Solve problems related to hydrostatic pressure and depth in fluid systems.

Suggested Learning Activities

- Demonstrate how the selection of piping materials, pumps and other materials is based on hydrostatic effects. (3.1, 3.5, 3.6)
- Demonstrate how a hydraulic brake system operates in an automobile. (3.1, 3.5, 3.6)
- Design a private septic system with consideration to the type of soil in the leach field. (3.1, 3.4)
- Identify the 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 examine Bernoulli's Principle. (3.5)
- Create a hydraulic arm powered by pistons that is capable of moving in three dimensions. (3.4, 3.6)
- 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 have to quadruple. (3.5, 3.6)

4. Energy and Power Technologies—Thermal Systems

Broad Concept: Thermal systems involve transfer of energy through conduction, convection, and radiation, and are used to control the environment.

- 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 used in the selection of materials, e.g., home and vehicle thermostat designs, circuit breakers.**
- 4.3 Identify the differences between open and closed thermal systems, e.g., humidity control systems, heating systems, cooling systems.
- 4.4 Explain how environmental conditions influence heating and cooling of buildings and automobiles.**
- 4.5 Identify and explain the tools, controls, and properties of materials used in a thermal system, e.g., thermostats, R Values, thermal conductivity, temperature sensors.

Boldface type indicates core standards for full-year courses.

Technology/Engineering, Grade 9 or 10

Learning Standards for a Full First-Year Course

Suggested Learning Activities

- Create a model to test the concept of conduction and compute heat losses, e.g., through the multi-layer wall of a building. (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 it has been heated, calculate the heat gains achieved through solar heating. (4.1, 4.5)
- 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 their solar cooker for her or his specific food. (4.1, 4.2)
- Design an awning for a business based upon the seasonal changes in the angle of the sun. (4.2)

5. Energy and Power Technologies–Electrical Systems

Broad Concept: Electrical systems generate, transfer, and distribute electricity.

- 5.1 Describe the different instruments that can be used to measure voltage, e.g., voltmeter, multimeter.
- 5.2 Identify and explain the components of a circuit including a source, conductor, load, and controllers (controllers are switches, relays, diodes, transistors, integrated circuits).**
- 5.3 Explain the relationship between resistance, voltage, and current (Ohm's Law).**
- 5.4 Determine the voltages and currents in a series circuit and a parallel circuit.**
- 5.5 Explain how to measure voltage, resistance, and current in electrical systems.**
- 5.6 Describe the differences between Alternating Current (AC) and Direct Current (DC).

Suggested Learning Activities

- 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 or lights. All of the motors in the system will operate at different speeds, or the lamps will operate at different intensities. (5.2, 5.3)
- Create schematics for series, parallel, and combination (series-parallel) circuits, and construct them from the schematics. (5.4)

Boldface type indicates core standards for full-year courses.

Technology/Engineering, Grade 9 or 10

Learning Standards for a Full First-Year Course

6. Communication Technologies

Broad Concept: The application of technical processes to exchange information includes symbols, measurements, icons, and graphic images.

- 6.1 Identify and explain the applications of light in communications, e.g., reflection, refraction, additive, and subtractive color theory.**
- 6.2 Explain how information travels through different media, e.g., electrical wire, optical fiber, air, space.
- 6.3 Compare the difference between digital and analog communication devices.
- 6.4 Explain the components of a communication system, i.e., source, encoder, transmitter, receiver, decoder, storage, retrieval, and destination.**
- 6.5 Identify and explain the applications of laser and fiber optic technologies, e.g., telephone systems, cable television, medical technology, and photography.**

Suggested Learning Activities

- Give an example 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 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)
- Explain what is meant by the size and focal length of a lens and its application for light theory. (6.5)
- Research a communication technology and the impact lasers or fiber optics have had on that technology. (6.4, 6.5)

7. Manufacturing Technologies

Broad Concept: Manufacturing processes can be classified into six groups: casting and molding, forming, separating, conditioning, assembling, and finishing.

- 7.1 Explain the manufacturing processes of casting and molding, forming, separating, conditioning, assembling, and finishing.**
- 7.2 Differentiate the selection of tools and procedures used in the safe production of products in the manufacturing process, e.g., hand tools, power tools, computer-aided manufacturing, three-dimensional modeling.
- 7.3 Explain the process and the programming of robotic action utilizing three axes.

Suggested Learning Activities

- 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)

Boldface type indicates core standards for full-year courses.

A Look at Energy Efficient Homes

Adapted from Standards for Technological Literacy, p. 197

Technology/Engineering, Grades 9–10

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.

The students in the technology classes were challenged to 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. The students had to work within a budget of \$150,000, and they had nine weeks to complete the project.

The students began by researching homes in their area that already incorporated features that were required in their home. 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 various practices and how they were integrating innovative features. For example, they 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 and energy-efficient systems and incorporating whole-home systems that are designed to provide maintenance, 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 and innovations, 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.

Assessment Strategies

- Students can research building codes and zoning laws in the community. Write a detailed report on the building codes and zoning laws.
- Students can compare construction efficiency of various house designs and evaluate the advantages and disadvantages of each design (e.g., ranch vs. colonial, lumber vs. steel framework). Create a chart illustrating the differences.

What It Looks Like in the Classroom

- Students can create an engineering presentation of the design, efficiency, and prototype using appropriate visual aids, e.g., charts, graphs, presentation software. Presentation may include any other factors that might impact the design of the house, e.g., the 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

- 1.1 Identify and explain the steps of the engineering design process, i.e., identify the 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.
- 1.2 Demonstrate knowledge of pictorial and multi-view drawings (e.g. orthographic projection, isometric, oblique, perspective) using proper techniques.
- 1.3 Demonstrate the use of drafting techniques with paper and pencil or computer-aided design (CAD) systems when available.
- 1.4 Apply scale and proportion to drawings, e.g., $\frac{1}{4}'' = 1'0''$.
- 1.5 Interpret plans, diagrams, and working drawings in the construction of a prototype.

Construction Technologies Learning Standards

- 2.1 Identify and explain the engineering properties of materials used in structures, e.g., elasticity, plasticity, thermal conductivity, density.
- 2.2 Differentiate the factors that affect the design and building of structures, such as zoning laws, building codes, and professional standards.
- 2.3 Calculate quantitatively the resultant forces for live loads and dead loads.

Energy and Power Technologies—Thermal Systems Learning Standards

- 4.1 Identify the differences between open and closed thermal systems, e.g., humidity control systems, heating systems, cooling systems.
- 4.4 Explain how environmental conditions influence heating and cooling of buildings and automobiles.

Appendices

Learning Standards by Grade Span, Grades PreK–8

GRADES 6 – 8

EARTH AND SPACE SCIENCE	LIFE SCIENCE	PHYSICAL SCIENCE	TECHNOLOGY/ENGINEERING
<ul style="list-style-type: none"> • Recognize, interpret, and be able to create models of the earth’s common physical features in various mapping representations, including contour maps. • Describe the layers of the solid earth, including the lithosphere, the hot convecting mantle, and the dense metallic core. • Differentiate among radiation, conduction, and convection, the three mechanisms by which heat is transferred through the earth’s system. • 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. 	<ul style="list-style-type: none"> • Classify organisms into the currently recognized kingdoms according to characteristics that they share. Be familiar with organisms from each kingdom. • 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. • Compare and contrast plant and animal cells, including major organelles (cell membrane, cell wall, nucleus, cytoplasm, chloroplasts, mitochondria, vacuoles). • 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. • Describe the hierarchical organization of multicellular organisms from cells to tissues to organs to systems to organisms. 	<ul style="list-style-type: none"> • Differentiate between weight and mass, recognizing that weight is the amount of gravitational pull on an object. • Differentiate between volume and mass. Define density. • 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. • Explain and give examples of how mass is conserved in a closed system. • 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. • 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). 	<ul style="list-style-type: none"> • Given a design task, identify appropriate materials (e.g., wood, paper, plastic, aggregates, ceramics, metals, solvents, adhesives) based on specific properties and characteristics (i.e.g., weight, strength, hardness and flexibility). • 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. • Identify and explain the safe and proper use of measuring tools, hand tools, and machines (e.g., band saw, drill press, sanders, hammer, screwdriver, pliers, tape measure, screws, nails, and other mechanical fasteners) needed to construct a prototype of an engineering design.

Learning Standards by Grade Span, Grades PreK–8

GRADES 6 – 8

EARTH AND SPACE SCIENCE

- 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).
- 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.
- 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.
- 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.

LIFE SCIENCE

- 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.
- 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.
- 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.
- 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).

PHYSICAL SCIENCE

- Give basic examples of elements and compounds.
- Differentiate between mixtures and pure substances.
- 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.
- Differentiate between physical changes and chemical changes.
- Explain and give examples of how the motion of an object can be described by its position, direction of motion, and speed.
- Graph and interpret distance vs. time graphs for constant speed.
- Differentiate between potential and kinetic energy. Identify situations where kinetic energy is transformed into potential energy and vice versa.
- Recognize that heat is a form of energy and that temperature change results from adding or taking away heat from a system.

TECHNOLOGY/ENGINEERING

- 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.
- Demonstrate methods of representing solutions to a design problem, e.g., sketches, orthographic projections, multiview drawings.
- Describe and explain the purpose of a given prototype.
- Identify appropriate materials, tools, and machines needed to construct a prototype of a given engineering design.
- Explain how such design features as size, shape, weight, function, and cost limitations would affect the construction of a given prototype.
- Identify the five elements of a universal systems model: goal, inputs, processes, outputs, and feedback.

Learning Standards by Grade Span, Grades PreK–8

GRADES 6 – 8

EARTH AND SPACE SCIENCE	LIFE SCIENCE	PHYSICAL SCIENCE	TECHNOLOGY/ENGINEERING
<ul style="list-style-type: none"> • Describe lunar and solar eclipses, the observed moon phases, and tides. Relate them to the relative positions of the earth, moon, and sun. • 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). • 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. • Recognize that the universe contains many billions of galaxies, and that each galaxy contains many billions of stars. 	<ul style="list-style-type: none"> • Give examples of ways in which genetic variation and environmental factors are causes of evolution and the diversity of organisms. • Recognize that evidence drawn from geology, fossils, and comparative anatomy provide the basis of the theory of evolution. • Relate the extinction of species to a mismatch of adaptation and the environment. • Give examples of ways in which organisms interact and have different functions within an ecosystem that enable the ecosystem to survive. • Explain the roles and relationships among producers, consumers, and decomposers in the process of energy transfer in a food web. • Explain how dead plants and animals are broken down by other living organisms and how this process contributes to the system as a whole. 	<ul style="list-style-type: none"> • Explain the effect of heat on particle motion through a description of what happens to particles during a change in phase. • Give examples of how heat moves in predictable ways, moving from warmer objects to cooler ones until they reach equilibrium. 	<ul style="list-style-type: none"> • Identify and explain the components of a communication system, i.e., source, encoder, transmitter, receiver, decoder, storage, retrieval, and destination. • 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). • Identify and compare communication technologies and systems, i.e., audio, visual, printed, and mass communication. • Identify and explain how symbols and icons (e.g., international symbols and graphics) are used to communicate a message. • Describe and explain the manufacturing systems of custom and mass production.

Learning Standards by Grade Span, Grades PreK–8

GRADES 6 – 8

EARTH AND SPACE SCIENCE	LIFE SCIENCE	PHYSICAL SCIENCE	TECHNOLOGY/ENGINEERING
	<ul style="list-style-type: none"> • 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. • 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. • Recognize that biological evolution accounts for the diversity of species developed through gradual processes over many generations. 		<ul style="list-style-type: none"> • Explain and give examples of the impacts of interchangeable parts, components of mass-produced products, and the use of automation, e.g., robotics. • Describe a manufacturing organization, e.g., corporate structure, research and development, production, marketing, quality control, distribution. • Explain basic processes in manufacturing systems, e.g., cutting, shaping, assembling, joining, finishing, quality control, and safety. • Describe and explain parts of a structure, e.g., foundation, flooring, decking, wall, roofing systems. • 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). • Explain how the forces of tension, compression, torsion, bending, and shear affect the performance of bridges. • Describe and explain the effects of loads and structural shapes on bridges.

Learning Standards by Grade Span, Grades PreK–8

GRADES 6 – 8

EARTH AND SPACE SCIENCE

LIFE SCIENCE

PHYSICAL SCIENCE

TECHNOLOGY/ENGINEERING

- Identify and compare examples of transportation systems and devices that operate on each of the following: land, air, water, and space.
- Given a transportation problem, explain a possible solution using the universal systems model.
- Identify and describe three subsystems of a transportation vehicle or device, i.e., structural, propulsion, guidance, suspension, control, and support.
- Identify and explain lift, drag, friction, thrust, and gravity in a vehicle or device, e.g., cars, boats, airplanes, rockets.
- Explain examples of adaptive or assistive devices, e.g., prosthetic devices, wheelchairs, eyeglasses, grab bars, hearing aids, lifts, braces.
- Describe and explain adaptive and assistive bioengineered products, e.g., food, bio-fuels, irradiation, integrated pest management.

Core Learning Standards for a Two-Year Integrated Science Sequence

GRADES 9 & 10

EARTH AND SPACE SCIENCE	BIOLOGY	CHEMISTRY	PHYSICS
<ul style="list-style-type: none"> • Explain how the transfer of energy through radiation, conduction, and convection contributes to global atmospheric processes, e.g., storms, winds. • Explain how the revolution of the earth and the inclination of the axis of the earth cause the earth's seasonal variations (equinoxes and solstices). • Explain the dynamics of oceanic currents, including upwelling, density and deep water currents, the local Labrador Current, and the Gulf Stream, and their relationship to global circulation within the marine environment and climate. • Describe how glaciers, gravity, wind, temperature changes, waves, and rivers cause weathering and erosion. Give examples of how the effects of these processes can be seen in our local environment. • Explain how water flows into and through a watershed, e.g., aquifers, wells, porosity, permeability, water table, capillary water, runoff. 	<ul style="list-style-type: none"> • Describe the composition and functions of the four major categories of organic molecules (carbohydrates, lipids, proteins, and nucleic acids). • Relate cell parts/organelles to their functions. • Differentiate between prokaryotic cells and eukaryotic cells, in terms of their general structures and degrees of complexity. • Distinguish between plant and animal cells. • Explain the role of cell membranes as a highly selective barrier (diffusion, osmosis, and active transport). • Provide evidence that the organic compounds produced by plants are the primary source of energy and nutrients for most living things. • Explain the interrelated nature of photosynthesis and cellular respiration. • Describe and compare the processes of mitosis and meiosis, and their role in the cell cycle. 	<ul style="list-style-type: none"> • Identify and explain some of the physical properties that are used to classify matter, e.g., density, melting point, and boiling point. • Explain the difference between mixtures and pure substances. • Describe the four states of matter (solid, liquid, gas, plasma) in terms of energy, particle motion, and phase transitions. • Identify the major components of the nuclear atom (protons, neutrons, and electrons) and explain how they interact. • Compare nuclear fission and nuclear fusion and mass defect. • Explain the relationship of an element's position on the periodic table to its atomic number and mass. • Explain how atoms combine to form compounds through both ionic and covalent bonding. • Balance chemical equations by applying the law of conservation of mass. • Describe the process by which solutes dissolve in solvents. 	<ul style="list-style-type: none"> • Explain the relationship between mass and inertia. • Interpret and apply Newton's first law of motion. • Interpret and apply Newton's second law of motion to show how an object's motion will change only when a net force is applied. • Understand conceptually Newton's law of universal gravitation. • Interpret and provide examples that illustrate the law of conservation of energy. • Relate thermal energy to molecular motion. • Differentiate between wave motion (simple harmonic nonlinear motion) and the motion of objects (nonharmonic). • Recognize the measurable properties of waves (e.g., velocity, frequency, wavelength) and explain the relationships among them. • Distinguish between mechanical and electromagnetic waves.

Core Learning Standards for a Two-Year Integrated Science Sequence

GRADES 9 & 10

EARTH AND SPACE SCIENCE	BIOLOGY	CHEMISTRY	PHYSICS
<ul style="list-style-type: none">• 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.• Describe the absolute and relative dating methods used to measure geologic time, e.g., index fossils, radioactive dating, law of superposition, and cross-cutting relationships.• Trace the development of a lithospheric plate from its growing margin at a divergent boundary (mid-ocean ridge) to its destructive margin at a convergent boundary (subduction zone). Explain the relationship between convection currents and the motion of the lithospheric plates.• 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.	<ul style="list-style-type: none">• Describe the structure and function of DNA, and distinguish among replication, transcription, and translation.• Use a Punnett Square to determine the genotype and phenotype of monohybrid crosses.• Describe how the taxonomic system classifies living things into domains (eubacteria, archaeobacteria, and eukaryotes) and kingdoms (animals, plants, fungi, etc.).• Explain how biotic and abiotic factors cycle in an ecosystem (water, carbon, oxygen, and nitrogen).• Use a food web to identify and distinguish producers, consumers, and decomposers, and explain the transfer of energy through trophic levels.	<ul style="list-style-type: none">• Identify and explain the factors that affect the rate of dissolving, i.e., temperature, concentration, and mixing.• Define Arrhenius' theory of acids and bases in terms of the presence of hydronium and hydroxide ions, and Bronsted's theory of acids and bases in terms of proton donor and acceptor, and relate their concentrations to the pH scale.	<ul style="list-style-type: none">• Describe the electromagnetic spectrum in terms of wavelength and energy, and be able to identify specific regions such as visible light.

Additional Activities to Enhance the Learning Standards

- Observe the effect of winter weathering on roads.
- *Discuss the scales (e.g., the Richter Scale) used to measure earth events. (T/E 2.2)*
- *Compare a beaver dam with a manmade 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 the earth's rotation and revolution. (T/E 2.2, 2.3)*

Standard #15

- Using a model (light source and sphere), demonstrate how the various phases of the moon are formed.

Grades 6–8

Standard #1

- Obtain a topographic relief map and a corresponding paper contour map of a coastal area (preferably in Massachusetts). Use both types of map 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 and the location of wildlife/plants.
- Use maps from different time periods to observe changes in landscape.

Standard #3

- Compare the heat absorption of white and black cans using a thermometer.
- Investigate heat transfer by placing plastic, metal, and wooden spoons in hot water and determining how quickly they heat up (conduction).
 - A) 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.
 - B) Investigate heat transfer *to* the 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.

Additional Activities to Enhance the Learning Standards

Standard #7

- Study the local landscape, and if possible also 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 notice and measure how high the tide came. 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

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)*
- *Build a terrarium containing plants and small animals, e.g., earthworms, other soil organisms, and 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)*

Additional Activities to Enhance the Learning Standards

Standard #2

- Examine a variety of nonliving and living things. Describe the 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 manmade objects engineered to enhance the senses or 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, etc.
- 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.
- Give students an animal and its habitat needs. Allow the students to imagine that they are that organism. Can they find what they need to survive, i.e., food, water, shelter/space?

Additional Activities to Enhance the Learning Standards

- *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 paper and pencil or graph paper as tools, sketch a drawing of the front view of the habitat. (T/E 1.3)*

Grades 3–5

Standard #2

- Observe the cross-section of various trees. Determine the age of the tree, and relate the variation in distance between the circles to the variation in climate from year to year.
- *Compare the physical properties of hard and soft woods (density, hardness, knots, etc.) and their use 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 frog 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, notice 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 fish. Explain how these adaptations help the fish survive.

Standard #7

- Discuss the challenges of living in a coastal environment. What stresses do plants and animals need to adapt to?

Standard #9

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

Standard #11

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

Additional Activities to Enhance the Learning Standards

Grades 6–8

Standard #12

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

Standard #13

- Look at the dispersal of pollen by bees and other insects to enable 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.

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 web sites) gathered by scientists who are conducting long-term ecological research. How are they monitoring sea level rises?
- Observe movement of barrier beaches seasonally. 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 timeframe that species have had to adapt, noting the impact of glaciation on ecosystems close to the poles.

Additional Activities to Enhance the Learning Standards

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

Standard #1

- Use 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 materials used are suited to the function of the overall object or some part of it.
- *Observe several common objects, discuss the different materials that they 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

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.

Topical Outline of the Science and Technology/Engineering Curriculum Framework

E A R T H A N D S P A C E S C I E N C E

BROAD TOPIC	GRADES PREK–2 TOPICS AND # OF LEARNING STANDARDS ()	GRADES 3–5 TOPICS AND # OF LEARNING STANDARDS ()	GRADES 6–8 TOPICS AND # OF LEARNING STANDARDS ()	GRADES 9/10 TOPICS AND # OF LEARNING STANDARDS (/)
Structure of the Earth System	Earth's Materials (2)	Rocks and their Properties (3) Soil (2)	Mapping the Earth (1) Earth's Structure (1)	Matter and Energy in the Earth System (12/14) Earth's Sources of Energy (0/6)
	Weather (1)	Weather (4)		
	Sun as a Source of Heat and Light (1)	Water Cycle (2)	Heat Transfer in the Earth System (2)	
Earth's History		Earth's History (1)	Earth's History (3)	Earth Processes and Cycles (9/22)
Earth in the Solar System	Periodic Phenomena (1)	The Earth in the Solar System (3)	The Earth in the Solar System (5)	The Origin and Evolution of the Universe (4/8)
# OF LEARNING STANDARDS	(5)	(15)	(12)	25 CORE/50 TOTAL

Topical Outline of the Science and Technology/Engineering Curriculum Framework

L I F E S C I E N C E

BROAD TOPIC	GRADES PREK-2 TOPICS AND # OF LEARNING STANDARDS ()	GRADES 3-5 TOPICS AND # OF LEARNING STANDARDS ()	GRADES 6-8 TOPICS AND # OF LEARNING STANDARDS ()	GRADES 9/10 TOPICS AND # OF LEARNING STANDARDS (/)
The Characteristics of Organisms	Characteristics of Living Things (2)	Characteristics of Plants and Animals (1)	Classification of Organisms (1)	Chemistry of Life (4/5)
		Plant Structures and Functions (1)	Structure and Functions of Cells (3)	Structure and Functions of Cells (9/10)
			Systems in Living Things (2)	Human Anatomy and Physiology (0/2)
Life Cycles and Heredity	Life Cycles (1)	Life Cycles (2)		
	Heredity (1)	Heredity (1)	Reproduction and Heredity (3)	Genetics (6/9)
			Evolution and Biodiversity (3)	Evolution and Biodiversity (3/3)
Organisms and their Environment	Living Things and their Environment (3)	Adaptations of Living Things (5)	Living Things and their Environment (1)	Ecology (2/5)
		Energy and Living Things (1)	Energy and Living Things (3)	
			Changes in Ecosystems Over Time (2)	
# OF LEARNING STANDARDS	(7)	(11)	(18)	24 CORE/34 TOTAL

Topical Outline of the Science and Technology/Engineering Curriculum Framework

P H Y S I C A L S C I E N C E S

BROAD TOPIC	GRADES PREK-2 TOPICS AND # OF LEARNING STANDARDS ()	GRADES 3-5 TOPICS AND # OF LEARNING STANDARDS ()	GRADES 6-8 TOPICS AND # OF LEARNING STANDARDS ()	GRADES 9/10 TOPICS AND # OF LEARNING STANDARDS (/)
Properties of Matter	Observable Properties of Objects (1)	Properties of Objects and Materials (1)	Properties of Matter (4)	Properties of Matter (4/4)
	States of Matter (1)	States of Matter (2)	Elements, Compounds and Mixtures (6)	Atomic Structure (4/11) Periodicity (4/4) Chemical Bonding (4/7)
Chemical Reactions				Chemical Reactions and Stoichiometry (3/6) Gases and Kinetic Molecular Theory Solutions (2/6) Acids and Bases (1/6) Equilibrium and Kinetics (1/5) Thermochemistry (0/4) Oxidation-Reduction and Electrochemistry (0/7)
# OF CHEMISTRY STANDARDS	(2)	(3)	(10)	25 CORE/67 TOTAL

CHEMISTRY

Topical Outline of the Science and Technology/Engineering Curriculum Framework

P H Y S I C A L S C I E N C E S (C O N T I N U E D)

BROAD TOPIC	GRADES PREK-2 TOPICS AND # OF LEARNING STANDARDS ()	GRADES 3-5 TOPICS AND # OF LEARNING STANDARDS ()	GRADES 6-8 TOPICS AND # OF LEARNING STANDARDS ()	GRADES 9/10 TOPICS AND # OF LEARNING STANDARDS (/)
Motion and Forces	Position and Motion of Objects (3)		Motion of Objects (2)	Motion and Forces (9/12)
	Energy	Forms of Energy Electrical Energy Magnetic Energy Sound Energy Light Energy	Forms of Energy Heat Energy	Conservation of Energy and Momentum (4/6) Heat and Heat Transfer (2/4) Waves (4/9) Electromagnetism (2/6) Electromagnetic Radiation (2/4)
# OF PHYSICS STANDARDS	(3)	(9)	(6)	23 CORE/41 TOTAL
TOTAL # OF PHYSICAL SCIENCE	(5)	(12)	(16)	48 CORE/108 TOTAL

Topical Outline of the Science and Technology/Engineering Curriculum Framework

T E C H N O L O G Y / E N G I N E E R I N G

BROAD TOPIC	GRADES PREK-2 TOPICS AND # OF LEARNING STANDARDS ()	GRADES 3-5 TOPICS AND # OF LEARNING STANDARDS ()	GRADES 6-8 TOPICS AND # OF LEARNING STANDARDS ()	GRADES 9/10 TOPICS AND # OF LEARNING STANDARDS (/)
Materials and Tools	Materials and Tools (3)	Materials and Tools (3)	Materials, Tools and Machines (3)	
The Engineering Design Process	Engineering Design (2)	Engineering Design (4)	Engineering Design (6)	Engineering Design (5/5)
The Designed World			Communication Technologies (4)	Communication Technologies (3/5)
			Manufacturing Technologies (4)	Manufacturing Technologies (1/3)
			Construction Technologies (4)	Construction Technologies (3/6)
			Transportation Technologies (4)	
			Bioengineering Technologies (2)	
				Energy and Power Technologies Fluid (2/6) Thermal (3/5) Electrical (4/6)
# OF LEARNING STANDARDS	(5)	(7)	(27)	21 CORE/36 TOTAL

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

The following list of broad 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.

I. The history of science

For this topic, students might study:

- 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 and technology in various countries over the centuries.

II. The nature of science

For this topic, students might study:

- 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.

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

III. Benefits of science and technology/engineering

For this topic, students might study:

- Major advances in standards of living in the 19th and 20th century, e.g., communications, transportation.
- Continuous progress in personal and public health, 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

For this topic, students might study:

- 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, and 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

For this topic, students might study:

- 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.

Facilities, Safety Practices, and Legal Issues

Realizing the vision of science and technology/engineering presented in this framework will take time, resources, collaborative planning, and commitment. Some issues of particular relevance to science and technology/engineering education are presented here, including the need for appropriate facilities and materials, attention to safe practices, curriculum coordination, and legal responsibilities.

Facilities and materials

Districts should work toward ensuring that students have the facilities and materials needed to undertake scientific and technological investigations in elementary, middle, and high schools. The facilities should include sinks, outlets, storage space for equipment and supplies, tables or other large surfaces where students can work, and ample areas where students can keep their projects for continued use over a number of classes. It is essential that students have appropriate quantities of materials and equipment in order to do hands-on, inquiry-based science, technology, and engineering.

Planning and providing adequate facilities is essential in the teaching and learning of science and technology/engineering. The Board of Education's Regulations on School Construction (603 CMR 38.00) set a standard of 1000-1200 square feet of space in science laboratories and up to 100 square feet per student in a technology/engineering facility for facility construction or renovation to qualify for state aid under the School Building Assistance Program. In addition to adequate floor space, proper ventilation and storage space are also needed. The Regulations on School Construction are available on the Department's website, www.doe.mass.edu.

Safe practices in working with tools, materials, equipment, and living organisms

Safety is a critical issue and an integral part of the teaching and learning of science and technology/engineering at all levels. It is the responsibility of each district to provide safety information and training, and the responsibility of each teacher to understand and implement safe laboratory practices. Many teachers ask their students to read and sign a safety contract, which helps ensure that students appreciate the risks of working in a laboratory. Examples of such contracts can be found at www.flinnsci.com/homepage/sindex.html and sun.menloschool.org/~tbuxton/chembio/safety.html.

There are many aspects to safe lab practices, including having appropriate protective equipment available, keeping the area clean and equipment in good working order, having appropriate disposal containers, providing sufficient accessible workspace, using proper storage and labeling, and having first-aid kits readily accessible. Proper use of and care for tools is a crucial part of learning science and technology/engineering, and teachers

Facilities, Safety Practices, and Legal Issues

should be conscious that their own behavior and use of the equipment will be modeled by students. Particular precautions should be taken in the handling of any living or nonliving organisms brought into the classroom. Organisms should come only from a reputable supplier. Teachers should be aware of and strictly observe safety measures in labeling, storing, and disposing of chemicals used the laboratory. Many schools are making efforts to minimize or entirely eliminate the use of mercury in the laboratory. Some traditional uses for mercury, e.g., making thermometers, can be done as effectively with water or other substances. When mercury is needed, you may wish to place a very small layer of water on top of the exposed mercury to prevent the mercury from vaporizing. The water will evaporate and you will have to replenish it. In experiments calling for balloons, be aware that latex balloons are a choking hazard for young children and that students of any age may have allergic reactions to latex.

There are many resources where teachers and administrators can learn more about safety in the classroom and in the lab. The Council of State Science Supervisors' informative brochure *Science & Safety: Making the Connection* is online at www.sargentwelch.com/html/pdfs/ScienceandSafety.pdf. Flinn Scientific (www.flinnsci.com) and the Laboratory Safety Institute (www.labsafety.org) also present comprehensive and useful material on many facets of laboratory safety.

Eye protection

It is critically important to make students aware of the hazards of working with chemicals and open flame in the laboratory and other settings, and to make every effort to protect students, in particular, to protect their eyes. As stated in Massachusetts G.L. Chapter 71, 55C:

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.

Facilities, Safety Practices, and Legal Issues

Legal issues

Administrators and teachers should know the Massachusetts laws that are relevant to science and technology/engineering education. These include regulations regarding safety, use and care of animals, storage of chemicals, and disposal of hazardous waste.

Dissection

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 do not choose to participate in actual dissections.

Further, as described in Massachusetts G.L. Chapter 272, 80G, 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).

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 Science and Technology/Engineering Curriculum Framework					
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 and technological concepts					
Incorporate applications of science and technology					
Highlight connections within science and technology 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, and the internet					

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

	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 disk, long-distance learning, CD-ROM, 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					

Glossary of Selected Terms

Adaptation modification of an organism or its parts that makes it 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, or signals.

Conductor A material capable of transmitting another form of energy (as heat or sound).

Constraint A limit to the design process. Constraints may be such things as appearance, funding, space materials, and 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 which it obtains by preying on other organisms or by eating particles of organic matter.

Decomposer Any of various organisms (as 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 wants or 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 thinking 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 wants and to winnow (narrow) down the possible solutions to one final choice.

Ecosystem The complex of a community of organisms and its environment functioning as an ecological unit.

Electric circuit The complete path of an electric current including usually 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.

Glossary of Selected Terms

Engineering The profession of or work performed by an engineer. Engineering involves 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 mankind.

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 (as climate, soil, and living things) that act upon an organism or an ecological community and ultimately determine its form and survival.

Erosion The gradual wearing away of rock or soil by physical breakdown, chemical solution, and 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 and other effects.

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

Gas/gas 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 (as of electricity or heat).

Life cycle The series of stages in form and functional activity through which an organism passes between successive recurrences of a specified primary stage.

Light An electromagnetic radiation in the wavelength range including infrared, visible, ultraviolet, and X rays and 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.

Glossary of Selected Terms

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

Magnetism A class of physical phenomena that include the attraction for iron observed in lodestone and a magnet, are inseparably associated with moving electricity, are exhibited by both magnets and electric currents, and are characterized by fields of force.

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 of a force or effect.

Metamorphic rocks Are formed from preexisting rocks that are subject to very high pressure and temperature, which result in the structural and chemical transformation of the preexisting rocks.

Metamorphosis A marked and more or less abrupt developmental change in the form or structure of an animal (as a butterfly or a 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 (as by the earth about the sun or by 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.

Glossary of Selected Terms

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 (as a green plant) which produce their own organic compounds from simple precursors (as carbon dioxide and inorganic nitrogen) and many of which are food sources for other organisms.

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

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 (as air) into another (as glass) in which its velocity is different.

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 material, including debris of organic origin, deposited as sediment by water, wind, or ice and then compressed and cemented together by pressure.

Simple machine 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 and 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, such as glass, concrete, and plastics.

Glossary of Selected Terms

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 the generation of 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 wants.

Technology Education A 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

Center for Improved Engineering & Science Education	www.k12science.org/
Curriculum Library Alignment and Sharing Project (CLASP)	www.massnetworks.org/clasp/clasp.html
Eisenhower National Clearinghouse for Mathematics and Science Education	www.enc.org
Flinn Scientific	flinnsci.com
Laboratory Safety Institute	labsafety.org
Massachusetts Department of Education	www.doe.mass.edu
PALMS Initiative	www.doe.mass.edu/palms
Science and Technology/Engineering Curriculum Framework	www.doe.mass.edu/frameworks/current.html
Massachusetts Comprehensive Assessment System (MCAS)	www.doe.mass.edu/mcas/
Mathematics Curriculum Framework	www.doe.mass.edu/frameworks/current.html
Classroom of the Future	www.cotf.edu/
National Science and Technology Week	nsf.gov/od/lpa/nstw/start.htm
National Science Education Standards: An Overview	www.nap.edu/readingroom/books/nses/html/overview.html
National Science Foundation	www.nsf.gov
National Science Teachers Association's Scope, Sequence and Coordination Project	www.gsh.org/nsta_ssandc/
Public Broadcasting System's (PBS) TeacherSource database	pbs.org/teachersource/
Science & Safety: Making the Connection	sargentwelch.com/html/pdfs/ScienceandSafety.pdf
Science and technology news and discussion	www.bottomquark.com/
TERC (mathematics, science, and technology/engineering curriculum programs)	terc.edu
The Futures Channel	www.thefutureschannel.com/home.htm
The Jason Project	jasonproject.org
Third International Mathematics and Science Study (TIMSS)	www.ustimss.msu.edu
World Book online database	school.discovery.com/homeworkhelp/worldbook/atozscience/

Selected Websites for Science and Technology/ Engineering Education

Earth and Space Science

Aeronautics and space resource for education	spacelink.nasa.gov/
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	www1.umn.edu/bellmuse/mnideals/belllive.html
Science and Technology-Consortium for International Earth Science Information Network	www.ciesin.org/
Up-to-the-minute images and news flashes of NASA's planned mission to Mars	mars.jpl.nasa.gov/2001/

Life Science

A guide to biology and chemistry educational resources on the web	biochemlinks.com/bclinks/bclinks.cfm
Food Science and Technology	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 Science

Amusement park physics	www.learner.org/exhibits/parkphysics/
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Technology/Engineering

Design It! Engineering in After School Programs	www.edc.org/CSE/projects/destech.html
Discover Engineering	discoverengineering.org
Education Development Center, Inc. (science and technology/engineering projects)	edc.org
FIRST (For Inspiration and Recognition of Science & Technology) Robotics Competition	usfirst.org
FIRST Lego League (integrates robotics technology into the LEGO building system)	legomindstorms.com/first/
How Stuff Works	howstuffworks.com
International Technology Education Association	www.iteawww.org
Internet Science Technology Fair	istf.ucf.edu/

Selected Websites for Science and Technology/ Engineering Education

Journal of Technology Education	vega.lib.vt.edu/ejournals/JTE/jte.html
Junior Engineering Technical Society	www.jets.org
Massachusetts Institute of Technology's <i>Technology Review</i>	www.techreview.com
Massachusetts Pre-Engineering Program	masspepinc.org
National Engineers Week Future City Competition	futurecity.org
PBS's Building Big series	www.pbs.org/wgbh/buildingbig/
Preview of The New York State Department of Education's 8th Grade Technology Assessment	emsc.nysed.gov/ciai/mst/techedtest/online.html
Project Lead the Way	pltw.org
Tech Directions Online	www.techdirections.com
Technological Horizons in Education	www.techweb.com
Technological Literacy Assessment	sasked.gov.sk.ca/k/p_e/eval/tl_overview/
Technology Student Association	www.tsawww.org
TechWeb	www.techweb.com
Texas Elementary Technology Education Lesson Plans	www.texastechnology.com
The Great Technology Adventure: Technology Literacy for Elementary School Children	tsaweb.org/competition/adventure.htm#Introduction
United States Department of Transportation	education.dot.gov



Massachusetts Department of Education

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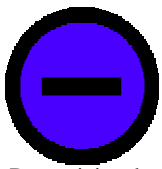


Science Examples



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Determining the Mass of an Electron (m_e)

J.J. Thomson
1856-1940

Cathode ray
experiment

Won the Nobel
Prize in Physics
in 1906

Showed that
cathode rays
were deflected
in an electric
field

Beam was
attracted to the
positive plate
and repelled by
the negative
plate

Since opposites
attract

Conclusion: the
cathode ray was
composed of
negatively
charged
particles

Cathode rays
are also
deflected in
magnetic fields

Particles were the same
regardless of the
materials used to make
the electrodes or the type
of gas used in the tube

Named them
electrons

$$e/m = E/B^2r$$

E, B, and r are
known
quantities

$$e/m = 1.76 \times 10^{11} \text{ C/kg}$$

Conclusion: the
negative particles
were common to
all kinds of atoms

$$m_e = 9.1 \times 10^{-31} \text{ kg}$$

Robert A. Millikan
1868-1953

Oil drop
experiment

Tiny droplets of
mineral oil

Gravitational
force caused the
droplets to fall
between two
parallel plates

Millikan adjusted the
electric field until
exactly balanced with
the gravitational force

Measured mass
of droplet in
absence of
electric field

Each carried an
electric charge

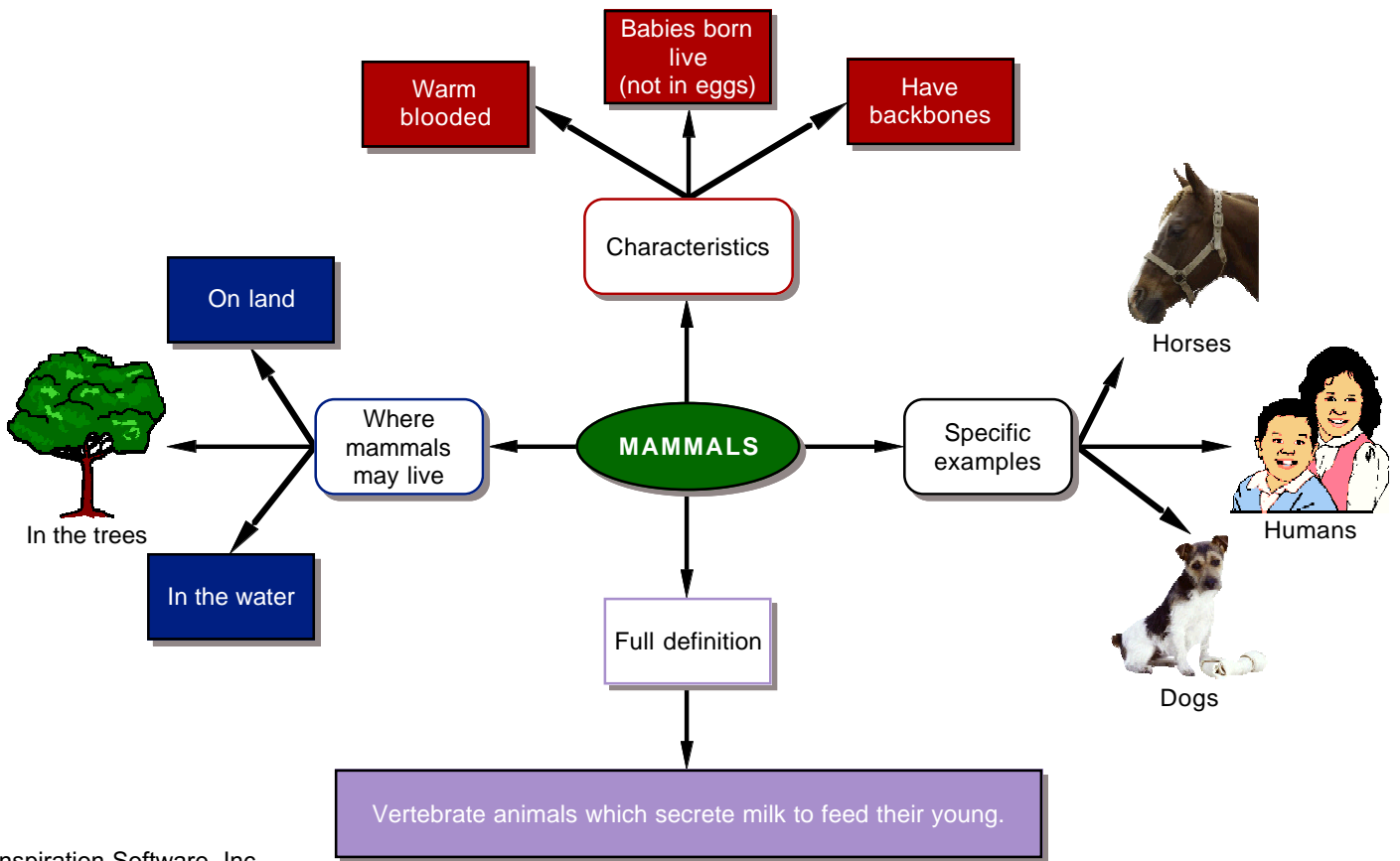
Oil droplets
became
suspended
between the two
plates

$$e = 1.6 \times 10^{-19} \text{ C}$$

$$qE = mg$$

$$q = mg/E$$

m, g, and E are
known
quantities



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SOUND

was first broken by

General Chuck Yeager

in a



named

"Glamorous Glennis"

after

Yeager's wife

Bell X-1

on

October 17, 1947

at

Muroc Dry Lake Beds, CA

now known as

Edwards AFB

whose

speed v

=

wave length

X

frequency f

which is called the

Wave Equation

is a

longitudinal wave

can travel in



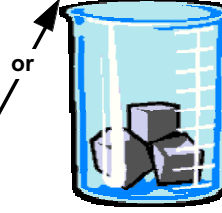
Gases

such as

air

whose

speed



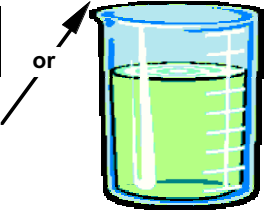
Solids

such as

steel

which travels

5000 m/s



Liquids

such as

water

which travels

1482 m/s @ 20° C

density

and

temperature

which vary with

altitude

which is a function of

frequencies

of

20-20,000 Hz

the range of

human hearing

15-50,000 Hz

the range of

canine hearing

1000-150,000 Hz

the range of

bat hearing

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