Massachusetts
Department of Education

Science & Technology Curriculum Framework

OWNING THE QUESTIONS

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Preface

The Massachusetts Science and Technology Curriculum Framework

Owning the Questions is one of seven curriculum frameworks that, along with the Common Core of Learning, lay the foundation for Massachusetts educational reform in teaching, learning and assessment. Like its companion frameworks in the Arts, English Language Arts, Health, Mathematics, Social Studies and World Languages, it was developed by practitioners working with staff from the Department of Education.

The Common Core affirms inquiry as central to teaching and learning. In classrooms that stress inquiry, students pursue questions that connect in important ways to their lives. The goal of inquiry based learning is for students to become questioners -- not just to know the questions, but to own the questions. The core concept of this framework, owning the questions, advocates that students participate so thoroughly in the activities of scientific investigation and technical design that they become the questioners themselves.

The guiding principles provide the basis for a detailed set of underlying beliefs and tenets central to owning the questions in science and technology. These nine guiding principles articulate the ideals of teaching, learning and assessing science and technology in Massachusetts. They contain illustrations of how educators create educational environments characterized by curiosity, persistence, respect for evidence, open mindedness balanced with skepticism, and a sense of stewardship and care.

The Science and Technology content section contains four strands that are broad learning standard statements about what students should know and be able to do as learners of science and technology. Each strand reflects the process of inquiry and the importance of owning the questions, by focusing on essential knowledge, skills and strategies that students need in order to become scientifically and technologically literate. A critical focus for these learning standards is teaching and learning that helps bridge the domains of science and foster integration of science and technology.

The Science and Technology framework is designed to be used in conjunction with the other six frameworks, and with the introductory common chapters. Together these chapters articulate a vision that will stimulate interdisciplinary learning both for young people and adults in Massachusetts school communities.

Developing The Massachusetts Science and Technology Curriculum Framework

Owning the Questions is based upon two reform initiatives in Massachusetts, the Education Reform Act of 1993 and Partnerships Advancing the Learning of Mathematics and Science (PALMS). PALMS is the Statewide Systemic Initiative, funded by the National Science Foundation in 1992. Of the seven initial goals for this initiative, the first was to develop, disseminate, and implement curriculum frameworks in Mathematics and Science and Technology. In January 1993, a set of recommendations for PreK-8 frameworks was produced by consultants from TERC, a research and development corporation based in Cambridge. Their work was reviewed by the PALMS Curriculum Framework Advisory Committee, and formed the basis for the later drafts of the mathematics and the science and technology frameworks. With the passage of the Massachusetts Education Reform Act in June 1993 and additional funding from the U.S. Department of Education, development of the curriculum frameworks was extended to include grades 9-12.

The creation of the science and technology curriculum framework was a collaborative endeavor among members of the Framework Development Committee--teachers, school and district administrators, scientists, college faculty, parents, and representatives of business and community organizations across the state. A majority of the members are currently classroom teachers who have extensive experience teaching science and technology at elementary, middle, and high school levels.

Core Concept: Owning the Questions and Overview

Why does an oil drop on water have color?

Why do some shoelaces come untied?

These simple questions open our minds to wonderful and complex ideas. Questions grow out of our basic encounters with the world, and questions are at the core of science and technology: *Why are things the way they are? Can we change them?*

As scientists and technologists raise questions and try to answer them, they become deeply engaged with their work. They wrestle with contradictions, puzzle through paradoxes, evaluate evidence, and search for connections. These pursuits require them to deal with the "real world"--both natural and human-made--and they often find that one question just leads to another. *Why does this happen? Why didn't that work?*

If students in Massachusetts are to learn about science and technology, they need to tangle with questions just as scientists and technologists do. They need to participate in projects, investigations, and design challenges that allow them to puzzle and search, raise questions, and rethink them. Like scientists and technologists, they must arrive at the essential content of science and technology through **Inquiry**.

The Massachusetts Common Core of Learning affirms the importance of Inquiry for all students learning to solve complex problems. This framework, like the others, builds on that understanding. **Inquiry** is at the heart of science and technology education.

Compare the work young students do in a Massachusetts classroom with the work a research team does in a business environment:

A Classroom

Fourth graders in a North Shore classroom are puzzled. The number of organisms in their salt water aquarium is decreasing. Together, they brainstorm reasons for this change in population. Is the water too warm or too salty? Are some organisms eating others? Several groups of students devise and carry out strategies for testing the theories. After a week of making observations and gathering data, each group organizes its data in charts and diagrams. The students then present their findings and reconsider their theories.

A Business Environment

A research team at Polaroid is trying to find a more environmentally-friendly package for their film.

What materials are biodegradable? How polluting is the manufacturing process? The team brainstorms ideas; uses on-line computer services to research materials; develops prototypes using those materials; and conducts focus groups with consumers. The team calculates development costs and projects the impact on sales, organizing this information in charts and diagrams. The team then presents its findings and recommendations to upper management.

Both fourth graders and the Polaroid team are engaged in Inquiry; the questions they ask drive the ways in which they approach their project. Their questions require them to propose hypotheses, decide upon and try out an approach, collect and interpret data, draw conclusions, and communicate the results to others. The students are learning science and technology not as collections of facts, formulas, and procedures, but as ways of proceeding and thinking.

In classrooms that stress inquiry, students pursue questions that connect in important ways to their own lives. In these classrooms, as in real life, inquiry and subject matter are inextricable.

In the early stages of any project, a teacher may need to identify the important questions for the class. But the goal of inquiry-based learning is for the students to become questioners themselves--not just to "know the questions" but to "own the questions." "Owning the questions" means participating so thoroughly in the activities of scientific investigation and technical design that students become confident, competent, and responsible investigators of the world around them. By owning the questions, students come to appreciate the power of the answers that science and technology afford them.

Technology is intimately connected to science and they are combined in this framework. Both adopt a reasoned approach to the world; both rely heavily on mathematics; and both are best learned through Inquiry. But science and technology are not identical. Science involves the discovery of fundamental relationships that help explain the natural world. In The Domains of Science, fundamental questions include

"What do I observe?"

"What is its nature?" and

"What if?"

Technology, on the other hand, creates tools that expand our capacities and help us solve problems we face. It extends human potential for controlling the natural and human-made environment. The Domain of Technology asks fundamental questions such as

"How does this work?"

"How can this be done?" and

"How can this be done better?"

The progress of science is dependent on technology. From bolts to bytes, science research relies so heavily on technology that most scientific advances can be traced to improvements in technology. Similarly, technical advances often occur when scientific understandings have been applied to a particular problem. More centrally, both science and technology are practices based in inquiry: asking questions, making conjectures, predicting, designing tests, solving problems, and rethinking ideas.

Finally and most importantly, science and technology are not abstract subject areas but integral parts of our daily lives, and they have significant impact on human life and the life of the planet. Questions like

"What are the implications of this?"

"Who benefits and who suffers?" and

"What should my town do about this?"

set science and technology in the context of Human Affairs. These are basic questions for those seeking a balance between economic well-being, stewardship of the earth, and quality of life (Solomon and Aikenhead, 1994).

As the Massachusetts Common Core of Learning declares in its preamble:

"Not so long ago, most Americans did not worry about their environment. Now, with the global population explosion, worldwide industrialization, increased use of natural resources and degradation of rain forests and agricultural land, students need to develop skills to analyze the environmental issues that face them today and that will challenge them tomorrow."

Overview

CORE CONCEPT

Owning the Questions

If students are to come to know and own the questions of science and technology, they need to engage with them the way scientists and technologist do. They wrestle with contradictions, puzzle through paradoxes, evaluate evidence, and search for connections. These pursuits require students to deal with the "real world" -- both natural and human-made -- and they often find that one question just lead to another.

In the chart below are the underlying beliefs and tenets central to owning the questions in science and technology and to the content for Science and Technology education in Massachusetts.

Guiding Principles of Science and Technology

1. Significant science and technology learning builds on students' curiosity and intuitions.
2. Investigation and problem solving are central to science and technology education.
3. Students learn best in an environment that acknowledges, respects and accommodates each learner's background, individuality and gender.
4. Assessment in science and technology is an opportunity for student learning, a tool for guiding instruction, as well as a way to document student progress.
5. Science and technology connect with other disciplines, and have a particularly integral relationship with mathematics.
6. A comprehensive PreK-12 Science and Technology program includes all sciences every year. Emphasis on the underlying principles of each discipline and their connections across the domains of science is critical.
7. Science and Technology study in grades PreK-10 becomes differentiated in grades 11 and 12

based on students' interests and career goals.

8. Communication and collaboration are essential to teaching and learning in science and technology.
9. Access to the expertise of others is needed in order for teachers to implement the cross-domain and interdisciplinary approach advocated in this framework.

Habits of Mind

- Curiosity
- Open Mindedness Balanced with Skepticism
- A Sense of Stewardship and Care
- Respect for Evidence
- Persistence

Science and Technology Content

Strand & Strand Summaries (Each strand is supported by specific learning standards, Grades PreK-4, 5-8, 9-10, and 11-12)

Inquiry Strand

Lifelong learners are able to use the methods of inquiry to participate in scientific investigation and technological problem solving.

Domains of Science

Lifelong learners are able to understand and apply the principle, laws and fundamental understandings of the natural sciences.

Technology

Lifelong learners are able to understand and apply the design process and the use of technology in society.

Science, Technology and Human Affairs

Lifelong learners understand questions and problems of science and technology in the context of human affairs.

Guiding Principles

Guiding Principle I

Significant science and technology learning builds on students' curiosity and intuitions.

Children are curious and eager to make sense of what they observe. From the time they are old enough to explore and manipulate the objects around them, they are young engineers: taking things apart, putting them together, trying to figure out how things work. All learners ask questions of one another and of adults, and they strive to put their ideas into words, drawings, and actions. Children's inclination to ask questions and their existing ideas about the natural world are the starting points for learning.

Children also learn the habits, ideas, and values that are shared by their culture about science, technology, and their roles as learners. But not all students at a particular age have the same knowledge, skills, life experiences, cultural outlook, or access to resources. Students at the same grade level may have different understandings of the same ideas; they may have different interests; and they may use different strategies to demonstrate what they know.

To see what this principle looks like, consider this first-grade classroom, where science and technology are part of the students' daily activities.

Ms. Lane places a number of common objects -- rocks, seeds, bird feathers, earthworms, a cup of water, snails, pieces of wood, grass, a candle, a spinning top, toy car, balsa airplane, and other things -- on a table in the classroom science center. She encourages the children to pick up, smell, observe, draw, talk about, and write about the objects. The children are eager to look closely. They dismantle some of the toys and try to put them back together. While they work together in small groups, Ms. Lane listens to their ideas and asks them to talk, draw or write about what the objects are made of, which ones are alike, and how they might be arranged into groups. As the children describe their ideas, Ms. Lane introduces related concepts such as all objects have certain properties that help us describe them. She also introduces words like "soft," "hard," "round," and "sharp."

As the children continue to raise questions, Ms. Lane introduces another important scientific idea to investigate. "Which objects on this table do you think are alive? Which do you think are not alive? What qualities do live things have?" The students work cooperatively to place the objects into two groups, those they think are alive and those they think are not. This leads to much debate and questions: "Is fire alive?" "Is a seed alive?"

With Ms. Lane's guidance, these young children are beginning to engage in the process of inquiry. They are actively participating in scientific investigations and problem solving. When students are engaged in inquiry, they ask questions, describe problems, collect evidence, represent their ideas in writing or with models, design solutions to problems, and discuss their understandings with others. In doing so, learners develop a web of connected ideas about their world.

Guiding Principle II

Investigation and problem solving are central to science and technology education.

Investigations introduce students to the nature of original research. They are motivating and integrating enterprises. Problem solving situations create powerful learning environments. They increase students' understanding and retention of scientific and technological concepts, and they provide entry points for all learners.

The inquiry-centered classroom does not compromise the rigor of learning, nor does it lessen the importance of a teacher's knowledge and experience. It does require that districts and teachers make choices about which science and technology concepts to study in depth. In the inquiry-centered classroom, teachers guide student inquiries, decide when and how to intervene, and help students focus on important ideas and concepts.

After their explorations, Ms. Lane's students share their ideas in a class discussion and consider how they know whether something is alive. They listen carefully to one another's explanations and arguments. "Of course a rock is not alive," says Ally. "It doesn't move." "It'll move if I push it," says Juan, so they are not sure. There is disagreement about fire. With their teacher's help, they observe a lit candle and consider what evidence there is that the flame is alive or not alive. From their consideration of evidence, Ms. Lane helps the students to make a list of the characteristics of living and non-living things.

Ms. Lane introduces the students to some new "members" of the class -- land snails. She asks the students to observe the snails closely, thinking about their list of characteristics, and to say why they think the snails are alive or not alive. During the year, the children return to the question of alive or not alive, amending their list of characteristics as they gain more experience and confidence.

Each student in this class builds meaning by integrating his or her new experiences with prior understandings. As in the debate about "what is alive," contradictions and confusion are a critical part of the ongoing process of learning. Students' ideas in science and technology evolve over time. Children need opportunities to examine and challenge their ideas so that they can learn how to apply these ideas to problem-solving situations. Opportunities for students to reflect on their own ideas, make predictions, and discuss their findings are crucial to this building of knowledge.

On the other hand, students must also realize that there are accepted truths (e.g. law of gravity) about the natural world that society has come to share. Many of students' early understandings, such as their tendency to believe that certain non-living things are alive, are brought into question by focused experiences with objects and processes in the world during their early childhood and primary grades, as well as later on in life.

Guiding Principle III

Students learn best in an environment that acknowledges, respects, and accommodates each learner's background, individuality, and gender.

All students, regardless of culture, background, gender, physical ability or developmental level, should have the opportunity to learn science and technology. The successful science and technology program will meet students' different interests, motivations, and strategies for learning while holding all students to high expectations and standards for accomplishment.

Ms. Lane's students are surprised to find that Ahmed, a child from Saudi Arabia, does not recognize a number of the seeds and shells on the table, not even the pine cone. The other children try to explain to him what pine cones are and what they know about them. Eventually they turn to the classroom computer and CD ROM to show him pictures of pine trees and pine cones. The next day, Ahmed brings in a new object and adds it to the table. The children puzzle over it. They cannot find it in any of their books. Finally Ahmed tells them the secret: "It is a cardamom seed. My mother uses it in cooking."

Society needs the contributions that women and minorities can bring to science and technology. While the idea that science and technology should be accessible to everyone has been growing in the past years, educators still need to pay attention to what each learner brings to these disciplines and to the kinds of support that all students need to succeed. This is especially true for women and minorities.

Students who arrive in our schools with a different cultural background and language may fall behind in science and technology while trying to master English. Some educators have begun helping transitional bilingual, English as a Second Language and Limited English Proficiency students to study science and technology in their native language while at the same time teaching them English. These teachers benefit from a clearer picture of the students' understandings and their ways of solving problems.

As students begin pursuing investigations and design challenges in more than one language, they in turn become aware of their own understandings and of the need to communicate these clearly to speakers of other languages.

What follows is a look at an innovative science and mathematics program in another Massachusetts classroom.

Cheche Konnen is an urban science and mathematics program that demonstrates the power of a sense-making approach for language minority students. In Haitian Creole, Cheche Konnen means "search for knowledge," and in the Cheche Konnen project, what students actually think is at the center of their activity. Cheche Konnen students explore their own questions; design their own studies; collect, analyze, and interpret their data; argue theories of their own making; and evaluate their evidence. Interdisciplinary investigations link science, mathematics, and language to inquiry. Through this approach, language minority students learn to think, talk, and act scientifically.

In their Water Taste Test investigation, for example, students decided to investigate a long-held belief in their school: the idea that the water fountain used by older students had better tasting water than the one used by younger students. The sixth graders who investigated this belief used their native Haitian Creole to design their studies, interpret data, and argue theories. They used English to collect data from their mainstream peers, read standards for interpreting test results, and report their findings. As they conducted their investigations and presented their findings, their mainstream peers began to see them as doing something important.

Their teacher remarks: "I think that the kids' way of seeing the world, and the way they think in general, has changed because they now feel more comfortable learning and investigating questions on their own. Most of all, I feel they have made a step towards being critical about what people tell them. They are learning to find out for themselves and not believe everything they hear."

The core strategy of approaching science and technology through inquiry can provide an equal footing for all students by allowing them to ask questions embedded in their own culture and particular interests. Acknowledging students' differences, teachers can plan investigations and design challenges so that students tackle problems and questions in multiple ways and in collaborative groups that respect each member's contribution to the whole.

Guiding Principle IV

Assessment in science and technology is an opportunity for student learning, a tool for guiding instruction, and a way to document student progress.

The goal of assessment is to provide teachers and students with information about students' evolving understandings, skills, and knowledge. Assessment that is embedded in the learning and teaching process offers non-judgmental feedback as well as an opportunity for students to practice skills and apply what they have learned in a new context. It helps teachers make informed judgments about their course of instruction. (Please see Chapter 2, Lifelong Learning, Teaching, and Assessment for an elaborated discussion of assessment).

Even as Ms. Lane was introducing the objects on the science table to her students, she was listening carefully for their ideas and keeping track of the ways individual students were expressing their understandings. If the children had difficulty understanding the idea of "properties," she was prepared to introduce more objects and to give the children more time to be comfortable with the concept before moving on to the question of "living or non-living."

Learning of science and technology requires multiple assessment strategies and multiple types of data. Using multiple strategies for assessment also respects children's differences and provides support and opportunities to learners with special needs, whether these needs are related to cognition, gender, language, or culture.

Performance-based assessment (as described in Chapter 2), meets the instructional goals of this framework particularly well because it allows students to demonstrate what they have learned and understood in the context of solving a complex problem. Performance-based assessment poses open-ended problems that are grounded in real-world contexts; the assessment strategy requires students to refine the problem, devise a strategy for solving it, conduct sustained work, and deal with concepts rather than discrete facts (Baron, 1990).

Imagine students in a tenth-grade chemistry class considering the properties of various substances:

> At Natick High School, Ms. O'Keefe challenges her chemistry students to a two-week research project designed to support their understanding of the physical properties of substances. The project will both help the students to become informed consumers and give Ms. O'Keefe important assessment information to inform her teaching. Ms. O'Keefe challenges the students to select three products -- a food product, a pharmaceutical product, and a household product -- and to explore their characteristics and physical properties. Consideration includes the densities, weights, and boiling and melting points of the chemical compounds in snack foods; the uses and side effects of pharmaceutical products; and the sometimes surprising chemical contents of common household products. Students display their findings on posters and share their research with their classmates. A scoring rubric and feedback to students with regard to the completeness and accuracy of their work provide assessment information. The students use this information to evaluate their progress, while Ms. O'Keefe uses it to plan the next month of laboratories and investigations.

Guiding Principle V

Science and technology connect with other disciplines, and have a particularly integralrelationship with mathematics.

One of the goals of the Massachusetts frameworks is to emphasize connections among disciplines. Issues related to science and technology should be examined in all disciplines; conversely, the questions of other disciplines should be related to science and technology.

The discipline of mathematics plays a particularly important role in technology and science. Too often students are shut out of science and technology, and ultimately out of careers, because of limited confidence and skill with mathematics. It is therefore crucial to bring these disciplines closer together in learning.

The world is often contemplated through the language of size, shape, and relationship. Mathematics allows us to analyze patterns we might not otherwise find among the details of our observations, and it lets us connect phenomena that might otherwise seem unrelated. Mathematics also helps us to construct models that describe the growth and change we see in the worlds of physics and biology, starting with simple number series and ranging through calculus. These mathematical models can also help us analyze and test complex technological systems such as the control of traffic through Boston's Central Artery or the structural integrity of the John Hancock building.

Mathematics, science, and technology also meet in data analysis, where counting, sorting, describing, graph making, comparing, and predicting all become part of a common language.

When science, technology, and mathematics curricula are interwoven, many perspectives enrich students' symbolic understandings, as illustrated in the following vignette.

Mr. Rowe presented his eighth graders with a scientific challenge, asking why small mammals usually have higher heart rates than larger ones and why they need to eat more food relative to their body weight. Students were encouraged to use simple geometric shapes to model the more complex shapes of animals; in this way, they could more readily see what effects changes in dimensions might have.

At the start of the challenge, students explored the relationship between the surface area and the volume of various sized boxes; they also represented the patterns they noticed. Their focus then shifted back to the original questions. Using their new mathematical understandings, the students considered the relationship between the volume and the surface area of various organisms. How would the volume and surface area of a mouse compare to those of an elephant? Why might organisms with more surface area to volume have faster heart rates and relatively greater oxygen consumption? How does this information relate to heat flow and heat loss?

Students' considerations were enriched by data about animals' food intake, energy expenditure, and the "costs" of daily life for a range of mammals. Through the use of simple models and some basic mathematics, Mr. Rowe's students came to see how body size places absolute constraints on the kind of life an organism can live -- with consequences down to the cellular level and up to the level of the ecosystem.

Guiding Principle VI

A comprehensive PreK-12 Science program includes all sciences every year. Emphasis on the underlying principles of each discipline and connections across the domains of science is critical.

Science and technology instruction in an integrated curriculum is necessary for all students every school year. Although each domain of science has its particular approach and area of concern, students need to see how the domains together present a coherent view of the world. Oceanographers, for instance, use their knowledge of physics, chemistry, biology, and earth and space sciences when they study organisms in a tidal pool.

Traditional instruction, in an approach called the "layer cake," has divided science education into three separate curricula: life sciences, physical sciences, and earth and space sciences. Recently, science education reformers in the United States have come to assert that "the time has come for the . . . layer cake to be dismantled" (NSTA, 1992), fearing that when the domains are taught in isolation, students think that scientific concepts reach only tenuously across the domains, if at all. Connecting the domains of natural science with one another and with other disciplines should be a goal of science education reform.

Organizing instruction across the domains of science can be done in a variety of ways. One approach coordinates the traditional domains of science while retaining the boundaries of their learning standards; another integrates the learning standards across the domains by means of unifying concepts or topics. (Strand 2 of this chapter provides illustrative material). Deciding which approach a school district should take will require time and incremental planning.

One example of how the sciences might be related is through ecology projects that study the distribution and abundance of organisms, their interactions with each other, and their relationship to the non-living world. Earth, life, and physical sciences are all part of ecological investigations, and student teamwork can reflect the need to integrate specialties to make sense of some phenomena.

High school students explore the global carbon cycle to understand some of the dynamics of recent global climate changes, which have important policy implications for at least the next half-century. After investigating carbon physiology in animals, plants, and communities of organisms, the class tries to build a model of the carbon cycle that would allow them to predict carbon dioxide levels in the atmosphere for the next ten years.

One team bases its projection on data about the annual fluctuations of CO2 in the atmosphere, as reflected in an "average" year's data. A second team takes current estimates of the amounts and exchange rates of CO2 in earth, seas, and biosphere to make its prediction. A third team makes its predictions using data on CO2 emissions from human activity continent by continent. Each team is missing an important piece of the puzzle. It is not until the three teams come together and combine projections that they are able to see the important dynamics of this bio-geological cycle. Only then can students assess for themselves the relative importance of humans as participants in this planet-wide experiment.

Guiding Principle VII

Science and Technology study in grades PreK-10 becomes differentiated in grades 11 and 12 based on students' interests and career goals.

Just as it is important for all students to study sciences and technology every year in an integrated curriculum, it is also important that science and technology courses help students prepare for the workplace as well as for further study. Eliminating the general track in Massachusetts high schools has significant implications for the science and technology programs that districts provide. Upper-level courses must prepare students for science- and technology-rich workplaces as well as for lifelong learning.

Students in the upper grades should have the opportunity to choose from a menu of programs. These may include apprenticeship and worksite training, job corps programs, alternative learning centers, vocational/occupational programs, and college preparation. As students reach grades eleven and twelve, they choose science and technology programs that are most suited to their interests and career goals.

The Cambridge Rindge and Latin School offers an unusually varied and interdisciplinary menu to its juniors and seniors. The Rindge School of Technical Arts integrates vocational learning with academics by providing students with the opportunity to choose courses defined by one of four career paths: Arts and Communications, Business and Entrepreneurship, Health and Human Services, and Industrial Technology and Engineering. Each of these career pathways functions like a "concentration" or "major" in college, offering clusters of related courses, internships, and community projects. The school district developed an articulation agreement with a college in which a student may receive college credit for a course completed in grades 11 or 12.

For example, a junior interested in the Health and Human Services pathway might choose to train in peer health education while taking a Human Anatomy and Physiology course. The next year he might pursue a health career apprenticeship in a local hospital before going on to the workplace or college. Similarly, a student interested in the Industrial Technology and Engineering pathway might choose to take a course in her junior year called "Physics and Engineering." This innovative course requires that students construct equipment for science experiments. The next year this same student might take a Science and Technology seminar and spend a year-long technical internship at Polaroid.

Guiding Principle VIII

Communication and collaboration are essential to teaching and learning in science and technology.

The practice of science and technology is a social endeavor. Ideas are tested, modified, extended, and revisited by the scientific community over time. Working with others is an essential part of learning the practice of science and technology.

The social context of science and technology learning is important because it helps students make connections and demonstrate understandings. Learners need opportunities to think reflectively about their work and to discuss their ideas both with peers and with people who have more experience. When students try to communicate their ideas to others, they come to clarify and explain them; similarly, hearing other people's ideas sparks students to new scientific and technological thinking.

The following conversation takes place among fifth graders who are studying the trash that they produce in their school. They are collaborating through electronic mail with six other classes engaged in the same study. Their collaboration helps them to listen to and question the ideas of others, work with data, and solve problems:

"It can't be true. They can't have so much glass and plastic and so little paper!"

"I can't believe they throw away so much and recycle so little!"

"They must have hit the wrong key on the computer and sent the wrong weight -- they must have!"

"Ms. Keely, what do you think? Did they do this wrong or what?"

These students are looking at a data table that contains the weights of trash collected over a week by six other classes. They have been studying trash output for the last month, and they have been carefully weighing their lunchroom and classroom trash to see how much trash they produce. Determining the proportions of glass, plastic, paper, and food trash is an important part of the exercise since it mirrors the ways in which recycling and waste management occurs. They have sent e-mail letters to other classes engaged in the same study of "Too Much Trash?", and they know that one class, like their own, has a pattern of bringing lunches from home. The animated conversation we hear is in reaction to an unexpected difference in the percentage of paper, plastic, and glass generated by this class and their own.

After another series of letters back and forth, the students discover the root of the discrepancy. It's juice boxes! They have weighed their juice box trash (which is significant: 25 boxes each day for 5 days) and counted it as paper, while the other class has weighed their juice box trash and counted it as 1/3 paper, 1/3 plastic and 1/3 glass. That's why the weights are so different.

By collaborating, sharing data, and making sense of data, fifth-grade students come to understand one of the most important tenets of science and technology: Measurement procedures must be standardized, and researchers must have agreed upon categorization and classification schemes in order to collect and analyze useful data.

Guiding Principle IX

Access to the expertise of others is needed in order for teachers to implement the cross-domain and interdisciplinary approach advocated in this framework.

Interdisciplinary learning requires cross-discipline planning, PreK-twelve coordination and sharing of resources among teachers. Teachers who have traditionally focused their science learning and training in one subject area need access to the expertise of their colleagues so they may coordinate across the domains. They also need opportunities for sharing the teaching of units and projects. Moreover, all teachers -- even accomplished inter disciplinarians -- benefit from time and professional development periodically dedicated to experiencing inquiry in science and technology for themselves. Fresh discoveries by teachers facilitate inquiry in students.

These recommendations will take significant time and collaborative effort on the part of teachers, district leaders and such educational partners as universities, communities, and businesses. The successful reform of science and technology education depends on whether the structure and culture of schools can provide support and encouragement for this to happen. As schools and districts invest time for establishing and maintaining teacher partnerships, they lay a foundation for successful implementation of this framework. Chapter 4, Charting a Course for the Future, provides guidance regarding this challenge.

Many teachers in Massachusetts have created powerful programs for integrating science, mathematics, and technology learning, and integrating these disciplines with social studies, English language arts, and all other areas of the curriculum.

A seventh grade teaching team designed an interdisciplinary project around the topic of hydroponic farming. Team members included teachers from technology, science, mathematics, instructional (computer) technology, social studies, language arts, and art.

The team challenged their cluster students to design, construct, and evaluate a hydroponic farming system. Each team of students received seeds and nutrient solution, and their systems were set up in a constant environmentwith uniform light and heat. Constraints included a limit on the number of plants that could be grown and a space limitation of 3,000 cubic centimeters. Students could modify their systems at any time, and they were challenged to design their own nutrient solutions. After one month, total growth was determined by measuring the cumulative height of all living plant matter.

In this initial phase of the project, the technology, science, and mathematics teachers shared information to help the students set up actual hydroponic systems and maximize their productivity. Working in small groups, students designed and built their hydroponic unit, studied plant growth and structure, recording changes in their science journals. They learned how to measure volume so they could keep within the parameters of the challenge, and they graphed root growth against stem growth using a variety of techniques. When a group of students reconfigured the tubing of their nutrient delivery system and accidentally drowned a third of their plants, the technology teacher asked the students to raise several possible explanations.

In the second phase of the project, the instructional (computer) technology teacher, social studies and language arts teachers were called on to help design activities that would allow students to understand the implications of their work in hydroponic farming. The instructional (computer) technology teacher proposed modeling the classroom systems as actual businesses, and taught the students a modified spreadsheet system for documenting their farm operation expenses. After hearing the social studies teacher lead a discussion about the transformation of the United States from an agricultural society to an industrial one, the language arts teacher came up with a writing activity. Working in teams, the students would write science fiction stories about hydroponic farming in the future. The art teacher lent support at all phases of the project, teaching illustration and demonstrating how different graphics treatments might influence the reading of data and the effectiveness of the science fiction story lines.

Students kept records of their learning, including sketches of ideas, possible solutions, technical drawings, graphs of the growing system's performance over time, and a cost analysis of production. The hydroponics interdisciplinary project culminated in a presentation to parents, and other members of the community, in which each group presented their findings and discussed the important implications of their work.

Habits of Mind

The habits of mind necessary for science and technology reflect the underlying philosophy of the Massachusetts Common Core of Learning.

Curiosity

At the heart of science and technology is the invitation to pursue questions about our world. Children meet these questions with an innate curiosity that effective teaching can bend gently toward science. Sometimes curiosity resembles puzzlement or confusion. Other times it resembles fascination, amazement, looking closer, revising ideas, and persistence. Curiosity in all its forms needs to be encouraged and kept alive in our students if they are to embrace science and technology.

Open Mindedness Balanced with Skepticism

Advances in science and technology depend on our staying open to new ideas and then examining them with a critical eye. Those who practice science and technology ensure the credibility of theories and the usefulness of new technologies by generating hypotheses and defining what evidence would be needed to support them. To attain rigor in these disciplines, students must learn to suspend disbelief, entertain new ideas, and be wary of information not supported by good evidence. They must also recognize that all theories remain ever open to reconsideration.

A Sense of Stewardship and Care

Science and technology affect human well-being and environmental quality at almost every turn. As students come to understand this, they develop an idea of stewardship: an appreciation for the richness and diversity of Earth's resources and a sense of responsibility for protecting human beings and the environment that sustains them now and for generations to come. Stewardship in science and technology also entails a sense of reasoned action that leads to safe behavior and a respect for all materials, tools, and life forms which students use to carry out their investigations. Learning safe and responsible practices is critical at all levels of science and technology study. A discussion of safety and material concerns is found in Instructional Resources and Materials section of this framework.

Respect for Evidence

Evidence is the backbone of scientific and technological understanding. Students must learn to respect the importance of data and testable hypotheses, just as they must appreciate the role pattern and predictability play in both the natural and human-made worlds. Honesty, accuracy, and the willingness to revise an idea or design when faced with contrary evidence are essential components of rigorous scientific proof and optimum design in technology.

Persistence

A tolerance for complexity and ambiguity help students persist in the face of messy data or procedural uncertainties. Willingness to risk failure, to begin again, to find a new strategy, or to fine-tune an existing one helps us to come up with better and better explanations and solutions in all areas of science and technology.

Habits of Mind Looks Like This . . .

Investigating Solar Homes

Ms. Albert's fifth graders are clustered into their design teams around four computers, each of them testing two model "solar houses" made of a different material. They have inserted a temperature probe into each house to measure how the inside air temperature changes when a lamp heats the outside of each house. The computer samples the temperature each second and draws a continuous line graph on the screen for each of the two probes, showing temperature over time. By comparing the heating and cooling curves of the line graphs, the students will learn how different materials affect the heating of the air inside, and then decide which materials would be best to use in a solar house in different parts of the country.

The class comes together to look at the graph printouts on the overhead and to discuss their findings. "Our glass house was the BEST," claims one girl, "cause it got real hot real fast." Several students point out that her group's glass house heated up 2deg.C more than the two similar glass houses tested by other groups. One member of another group said, "I wonder if that temperature is right, because it doesn't match the other two." The first girl said, "Of course it's right, the computer said so." Another student disagreed, "Just because the computer says so doesn't mean they did the experiment right."

The students had spent some time discussing what would make the test of all the houses "fair," and agreed that all the variables should be kept the same except for the type of material used in the model. Ms. Albert reminds them of this and asks the class: "What variables might have made a difference in the temperature of this house?" After some debate, each group goes back and measures how far the lamps were from the surface of each glass house. The first group discovers that their lamp was two inches closer than anyone else's. "Does that mean this group's answer is wrong?" asks Ms. Albert. The class is quiet for a minute, and then one student raises her hand. "I don't think they have the wrong answer, but they did the test differently from everyone else, so we can't use their data."

The class agreed that the data from the other two glass houses was very close, less than a half a degree different, and confirmed that their lamps were set up at the right distance. The students decide to let the first group adjust their lamp and redo the investigation to make sure the other two samples weren't just a fluke. When the first group gets the new results, their data is within a half degree of the others, and the class agrees they have enough information on glass now to move to the next stage in the curriculum.

As part of their study, Ms. Albert invites a community contractor to show how modern house construction is insulated.

Science and Technology Content Standards

CORE CONCEPT

Owning the Questions

If students are to come to know and own the questions of science and technology, they need to engage with them the way scientists and technologists do. Asking questions and evaluating evidence are central to this inquiry.

This core concept is further defined for the classroom by four strands that are broad statements about what students should know and be able to do as learners of science and technology. Each strand reflects the central rationale of the inquiry process and the importance of owning the questions by focusing on essential knowledge, skills, and strategies that students need in order to become scientifically and technologically literate.

Science and Technology Strands

Strand 1: Inquiry

Lifelong learners are able to use the methods of inquiry to participate in scientific investigation and technological problem solving.

Strand 2: Domains of Science

Lifelong learners are able to understand and apply the principles, laws, and fundamental understandings of the natural sciences.

Strand 3: Technology

Lifelong learners are able to understand and apply the design process and the use of technology in society.

Strand 4: Science, Technology, and Human Affairs

Lifelong learners understand questions and problems of science and technology in the context of human affairs.

Each Strand includes a narrative description, specific learning standards, and vignettes and examples that illustrate the standards in action.

Learning Standards:

These are organized by grade span and provide specificity with regard to what students should know and be able to do at the end of each grade span (PreK-4, 5-8, 9-10, and 11-12). During grades 11 and 12 options are designed to prepare students for post-secondary study in the liberal arts, technical fields, or the workplace. The options designated provide the main focus for the student's two years of study. However, it should be noted that internship experiences, technology-engineering courses, and in-depth, within-school study of key topics in the sciences and in technology are important options for all students.

These learning standards are equally applicable to the adult learners enrolled in learning centers throughout the state. Adult educators are strongly encouraged to implement the learning standards and adapt them according to the literacy and experiential levels of their students.

The National Science Education Standards developed by the National Research Council, Benchmarks for Science Literacy developed by the American Association for the Advancement of Science, and other state and national reform documents inform this effort. The work of The International Technology Education Association informs the technology standards.

Strand 1: Inquiry

Lifelong learners are able to use the methods of inquiry to participate in scientific investigation and technological problem solving.

As stated in The Massachusetts Common Core of Learning, all students should investigate and demonstrate methods of scientific inquiry and experimentation.

Before there was science or technology, there was inquiry. Questions like "What causes the seasons?" and "How can we grow more food each year on this land?" were asked by human beings long before science or technology became disciplines. Human beings are curious. They want solutions to everyday problems. And so they become scientists and technologists -- sometimes without even knowing it.

In the same way, inquiry in the classroom builds on students' own curiosity and practical-mindedness. It leads them to a deeper understanding of the world than they would get by just reading about it, and it leads them to discover governing principles instead of just memorizing them. Inquiry helps students to learn not just *"what we know"* but *"how we know."*

In the early school years, inquiry leads children to engage with the world. They make careful observations and talk about what they see. Through guided observations, they learn to notice as much as possible about objects and events and pay attention to details. At first, children record their observations in drawings; later, as their writing skills develop, they annotate their drawings. Gradually, a foundation for more quantitative inquiry is laid through activities such as collecting, grouping, and ordering familiar objects; noting similarities and differences among them; observing and talking about changes; and asking even more questions. Even very young children can make measurements using common objects found in the classroom, such as Unifix cubes; older children can learn to use conventional measuring tools accurately. By checking their observations and measurements against their ideas, and vice versa, children start to build strong conceptual understandings.

During the elementary school years, children come to realize that some of their questions can be answered by testing them. Investigations may be designed and carried out by the whole class. Later, students develop the skills needed to design and carry out their own tests, using specialized instruments and tools. Some tests will be scientific investigations, searching for understanding; for instance, students may try to discover why shadows fall in different directions. Other tests will take the form of technology design challenges, searching for workable solutions to problems; for instance, students may try to design a car that will stop before it rolls off the edge of a table.

In the middle grades, students plan and carry out more sophisticated tests and design challenges, gradually learning to distinguish relevant from irrelevant information. They also become more proficient with data, manipulating and analyzing it with confidence if not always with accuracy, and they can now more readily justify their conclusions with evidence. In middle school, science and technology learning continues to take place in the context of extended investigations.

In their high school years, students become better abstract and hypothetical thinkers. As they hone their analytical skills, they can design more rigorous scientific investigations and meet technology design challenges involving problems that have not necessarily been solved before. They now are more proficient at working with quantitative data, and they can represent it graphically and symbolically. They also get better at interpreting complex and messy data, creating models, making inferences, and using evaluative feedback to check specifications.

Inquiry skills built in grades nine and ten are expanded in grades eleven and twelve to include reflection on the assumptions and concepts that guide investigations and problem-solving activities. Students learn how to construct and evaluate their own scientific and technological explanations and to judge the work of others.

Questions are an integral aspect of **lifelong learning** and adult basic educators are strongly encouraged to implement these Inquiry Learning Standards and to adapt them to the literacy and experiential levels of their students.

Grades PreK-4 Learning Standards

- Observe and describe familiar objects and events, identifying details, similarities and differences.
- Ask questions, both investigable and non investigable, about the objects and events observed. Suggest ideas about, `how', `why', and `what would happen if'.
- Make predictions based on past experience with a particular material or object.
- Plan and conduct a simple investigation knowing what is to be compared or looked for.

- Extend observations using simple tools, e.g., hand lens, rulers, two-arm balance.
- Recognize and communicate simple patterns in data.
- Describe ideas about `how', `why', and `what would happen if'.
- Interpret findings by relating one factor to another, e.g., If a ball is dropped from a higher place, will it always bounce higher?
- Describe and communicate observations through discussions, drawings, simple graphs, and writing.

Grades 5-8 Learning Standards

- Note and describe relevant details, patterns, and relationships.
- Differentiate between questions that can be answered through direct investigation and those that cannot.
- Apply personal experience and knowledge to make predictions.
- Apply multiple lines of inquiry to address and analyze a question, e.g., experimentation, trial and error, survey, interview, and secondary sources.
- Design an investigation or problem specifying variables to be changed, controlled, and measured.
- Use more complex tools to make observations, and gather and represent quantitative data, e.g., microscopes, graduated cylinders, computer probes, stress and impact testers, wind tunnels and timers.
- Describe trends in data even when patterns are not exact.
- Reformulate ideas and technological solutions based on evidence.
- Analyze alternative explanations and procedures.
- Represent data and findings using tables, models, demonstrations and graphs.
- Communicate ideas and questions generated, and suggest improvements or alternatives to the experimental techniques used.
- Communicate the idea that usually there is more than one solution to a technological problem.
- Design a solution involving a technological problem and describe its advantages and disadvantages.

Grades 9-10 Learning Standards

- Distinguish those observations that are relevant to the question or problem at hand.
- Formulate testable questions and generate explanations using the results of predictions.
- Use a range of exploratory techniques, e.g., experiments, information/literature searches, data logging, research, and development, etc.
- Make decisions about the range and number of independent variables and how to control other variables in designing experiments.
- Select and use common and specialized tools to measure the dependent variable.
- Select appropriate methods of recording and interpreting data.

- Accurately use scientific and technological nomenclature, symbols and conventions when representing and communicating ideas, procedures, and findings.
- Select appropriate means for representing, communicating, and defending a scientific and technological argument.
- Question interpretations or conclusions for which there is insufficient supporting evidence, and recognize that any conclusion can be challenged by further evidence.
- Formulate further testable hypotheses based on the knowledge and understanding generated.
- Interpret data in the light of experimental findings, and appropriate scientific and technological knowledge and understanding.

Grades 11-12 Learning Standards

Inquiry during these years is characterized by work that builds upon the inquiry skills honed during grades 9 and 10, and expands them to include reflecting on the assumptions and concepts that guide student investigations. Students need to learn how to construct and evaluate their own and others' scientific and technological explanations, as well as learn how to evaluate evidence.

Example of Student Learning

Inquiry: Crossing the Domains of Science, and Connecting Science with Technology

PreK-4

Adopt A Tree

Second graders "adopt" the sugar maple just outside their classroom window. The tree becomes part of a year-long study about change and life cycles. They begin this study by listing observations about the maple and speculating about changes they think might occur over the course of the school year. Together, based on their discussion, they make a timeline of the predicted changes.

Their existing knowledge, observations and speculations serve as a starting place for posing questions. Some of their questions include:

- When will the leaves change color and fall from the tree?
- What is the difference between an old tree and a young tree?
- Is the soil under our tree the same as soil just beyond the tree?
- Is a tree's shadow always the same?
- What in our school is made from wood?
- What can we do to take care of trees?

These questions provide opportunities for addressing learning standards from each of the four strands and for integrating the three domains of science.

Together, the students plan and conduct an investigation to determine when and how the leaves on their tree will change. They choose a leaf hanging within reach and place a tag on the leaf stem. They then make weekly observations and drawings of the leaf, noting changes that have occurred since the previous week. Once leaves have fallen from the tree, students begin weekly or monthly observations of the developing buds, flowers, and new leaves.

Assessment Embedded in the Field Study

Students record their tree observations in journals. Their first drawings are kept and labeled and dated, so students can see how their observations and ideas change during the course of the project. The teacher develops strategies for assessment, such as a rubric for detail in observational drawings, and emerging `research' questions, which are shared with the students. Their records are mostly drawings with notes indicating the importance of particular details. Their teacher encourages them to write down new questions that surface during their explorations. At various times during the year students identify a journal entry "where they learned something special" and share this with their teacher and classmates. The teacher looks for evidence of children's attention to details of leaf structure, recognition of patterns, new questions, and indications that conceptual understandings about change are developing. After the last observation, students do a final drawing.

At the end of the year, students look back over their journal entries and select some examples of their work that they believe tell something important about what they have learned. These selections are each accompanied by a section where they reflect upon why the piece of work has been selected. The students each have a conference with the teacher to discuss the work they have chosen. These "portfolios" are presented to parents as documentation of important learning during the year.

Physical Sciences

Students become aware of the behavior of light and shadow when challenged to describe the size, shape, and location of the tree's shade. As part of their field study, they make drawings to show the relative position of the sun, the tree, and its shadow. After returning to the classroom, they compare the strategies they came up with and share findings. They then repeat their observations and data gathering later in the day and talk about the changes noticed. (Their shadow drawings are carefully labeled so they can be compared to ones done later in the project).

Life Sciences

Students begin to recognize variation in growth and development as each team compares the adopted tree to one nearby. The students are asked to decide whether they think their tree is older or younger than the others and to support their decision with evidence. Students also monitor the changes happening to other trees and plants in the area, to find out if they, too, go through cycles of dropping leaves in the fall, and growing buds and flowers in the spring. Some students decide to keep a chart of when each plant gets its first leaf in the spring.

Earth and Space Sciences

The students investigate properties in the earth's materials by collecting and comparing two soil samples -- one from under the tree and one from beyond the tree's canopy. The students separate each sample into various components, e.g., rocks, organic materials, living things, to see how they are the same and how they are different.

Technology

Students realize that many objects in their classroom are made from wood when they go on a "wood search." They learn that maple is hard wood and comes from broad-leaved trees, while trees with needles have soft wood. They look at how wood is used in constructing a building. A parent who works in the construction industry comes to class and talks about her work.

Science, Technology, and Human Affairs

Students begin to understand that we (as individuals, groups, and communities) can make decisions that change the natural environment by devising a plan for saving and recycling paper in their classroom.

Example of Student Learning

Inquiry: Crossing the Domains of Science, and Connecting Science with Technology

Grades 5-8

How Do Objects Fly?

Middle school students' study of flight begins with building and informally testing different types of gliders. The students explore features that make flight possible and variations in design that influence flight, e.g., weight, center of balance, wing size and wing span. These investigations serve as conceptual building blocks and catalysts that lead students to ask their own questions and pursue further inquiries. These include:

- Which glider flies the farthest? Which stays in the air the longest?
- What forces influence how a stunt glider and a distance glider fly?
- How is the structure of an eagle and that of a glider the same?
- How is flight affected by environmental factors such as wind and air pressure?
- How does purpose of the aircraft affect wing design?
- What impact does air traffic have on people and organisms in communities near an airport?

These questions provide opportunities for addressing learning standards from each of the four strands and for integrating the three domains of science.

Students develop the skill to design and conduct a scientific/technological investigation. After building and informally testing different types of gliders, the students devise controlled tests to determine how particular design features affect flight distance. Students evaluate the most effective design for a designated purpose.

Assessment Embedded in the Project's Work

The teacher shares the criteria for evaluation with her students. These include:

1. Accurate reporting of the design process and the testing procedures.
2. Clear presentation of results of trials in graph or other form.
3. An interpretation of the success of the design that takes into account its goals and outcomes.

Students' project glider and the data accompanying its test results are presented to the class. A team presentation includes input from each team member. This oral presentation includes sketches of design ideas, documentation of solution choices, and some technological history. At an open house, students' projects are shared with parents and other family members. Students record the obstacles and successes in their journals, and these reflections on their own progress are considered along with their teachers' evaluation of their work.

Physical Sciences

Students learn that several forces act on objects. These can be regarded as pushes or pulls and can either reinforce or cancel each other out. Students observe the flight of two gliders and explain variation in behavior with particular attention to the forces that are acting on each glider and the effects of different materials.

Life Sciences

Students develop understandings about diversity and adaptation of organisms as they compare the structure of an eagle's wing to that of a glider, taking into consideration form, size, and weight.

Earth and Space Sciences

Students develop understanding that objects on or near the earth are pulled toward the earth's center by gravitational force as they observe the behaviors of their gliders.

Technology

Students learn that transportation vehicles are designed for different purposes. As part of their study, they compare the wing structure of a passenger plane, a cargo plane, and an Air Force jet. Students learn that today's airplane is the result of cumulative work by men and women from various cultures and races.

Science, Technology, and Human Affairs

Students recognize that while technology can help us to manage societal and environmental problems, it can also have an impact on society and on the natural world, both positive and negative. Students interview nearby residents, environmentalists, and local officials to find out about the impact of air traffic on people and organisms near the airport.

Example of Student Learning

Inquiry: Crossing the Domains of Science, and Connecting Science with Technology

Grades 9-12

Effects of Oil Pollution on Ocean Ecosystems

Tenth graders begin a coordinated study of the effects of oil pollution on ocean ecosystems by immersing fresh water plants in oily water and observing reactions. This initial exploration leads them to ask to new questions, including:

- What is the impact of oil pollutants on salt water organisms?

- How do oil pollutants affect the transmission of light through the water?
- What is the impact of mining and shipping fossil fuels on ocean ecosystems?

These questions provide opportunities for addressing learning standards from each of the four strands and for integrating the three domains of science.

Each student team designs an investigation to determine the impact of oil-based substances on different biological systems, e.g., chemical change in the water, growth of microorganisms or water plants. Students extend their understanding of experimental design, meaningful data collection, dependent and independent variables, and positive and negative controls.

Assessment Embedded in the Project's Work

Students relate what they have learned to an actual oil spill in their local area. Using evidence and ideas from their prior investigations, they focus on one or more of the following important issues:

1. How have the pollutants in this specific oil spill blocked energy flow?
2. What is the flow of toxins?
3. What is the effect on the biosphere (immediate and long-term)?
4. What organisms are impacted and how?

Student teams prepare a presentation for their class that targets the implications of what they have learned for state or federal regulation. The presentations involve use of primary and secondary sources, and involve use of drawings, diagrams, and other forms of explanation to argue their points. Student presentations are evaluated at the team level, and each individual rates herself for her contribution.

Using this Framework for Interdisciplinary Planning . . .

Our Backyards: An Environmental Project with an Interdisciplinary Focus

Our Backyards is an environmental project that teachers designed with the help

of this framework (The Ten Mile River Project in the Science, Technology and Human Affairs Strand provided the inspiration). The project invites teachers and students to learn about their unique water address called a watershed. When a raindrop falls anywhere in the world it has to land somewhere and then flow to somewhere. The number of raindrops that fall on a watershed and where they fall controls the kinds and numbers of plants and animals, including people, that can survive at a certain water address.

The environmental focus crosses all subject areas as well as domains within the sciences. Real world problems are posed and students are invited to create real solutions.

In teachers' efforts to cross the domains of science, they first looked at the framework learning standards, selecting standards from the three domains of science, technology, as well as Science, Technology, and Human Affairs. These standards focus on the nature of the water cycle, geologic impacts on water flow, the chemical nature of water, interaction and interdependence of species within an environment, and the impact of human technology and activities on the land, and their resulting effects on the watershed.

The invitation to inquiry included the following questions for students to investigate:

- What is your watershed and how large is it? Look at the USGS Topographic Quadrangle that includes your school and community-using the highest elevations, find the boundaries of your local watershed. Where does the water flow? Does it go to a river or other body of water?

- How much rain falls each year on your school yard? What path does a raindrop take; if it lands on the grass, or if it lands in a parking lot? Look at the entire surface area of your school yard and determine how much water goes into the ground and how much runs off.
- What effect did the glaciers that advanced into New England and retreated 18,000 years ago have on the rocks and soils of your watershed?
- What plants and animals live on, under and over your watershed? What habitats do they require? Are there any endangered species?
- How do people use the land in your watershed? What is the impact of this use in your community? Where does your water use come from? Where does the waste go?
- Design a primary water filtration system.

When students planned and conducted investigations and research to explore these questions, they used teamwork to read and make maps, construct models, apply mathematical strategies, and interview local resource people.

In planning for the interdisciplinary collaboration within our school, it is clear that the following ideas connect to the other Massachusetts Curriculum Frameworks.

Social Studies

Students study global problems such as acid rain, ocean pollution and holes in the ozone. They use topographic maps and construct 3-D maps.

Students consider environmental legislation and collect opinions on local environmental issues. They attend public hearings or city council meetings. They work with organizations to assess or influence public opinion.

Students search networks for resource information, they collaborate with students in other watershed areas and construct maps and graphs of current or historical information.

Health

Students test for water quality, and test water conservation devices. Students identify which household products contain recyclable material and evaluate household hazardous products.

Mathematics

Students calculate the amount of rainfall in an area. They present their data in charts or graphs. They study population growth and change of living organisms.

Adult Learning Looks Like This . . .

Design-a-Park

Ms. Cruz, an adult basic educator in Lawrence, prepares students ranging in age from 17 through 25 for the General Equivalency Diploma. She has a degree in electrical engineering and as part of her teaching, encourages young women to pursue careers in mathematics and science. Her program, "Explorations in Math and Science" involves a project about their local environment.

I give my class the challenge and wonderful experience of designing a park. Their park needs to include a stream, a hill, and at least two trees. They need to figure out how to make their park safe and fun for all visitors, and stay within a budget of five thousand dollars. The students become seriously involved in all aspects of the project. They learn to organize information, visualize, make group decisions, use models, do scale drawings and compute.

Strand 2: DOMAINS OF SCIENCE

Lifelong learners are able to understand and apply the principles, laws, and fundamental understandings of the natural sciences.

There is a knowledge explosion of unprecedented proportion in the sciences. For educators, the problem of having too many topics, and too little time to develop them, is a serious one. Just as serious is the need for students to understand certain central concepts, laws, and theories that transcend the traditional domains of science (i.e., physical sciences, life sciences, and earth and space sciences), for only then can they successfully contribute to a society in which science and technology play an increasingly important part. Science education therefore needs to address a difficult, yet essential question:

What are the most central concepts, laws, and theories that we want students to understand and be able to use?

Crossing the domains of science provides the greatest challenge at the high school level, where the sciences are traditionally taught separately. Two approaches for relating central concepts across the domains of science are described below, with illustrations following each.

Crossing the Domains of Science:

A collection of ways for relating central concepts across physical, life, and earth and space sciences.

Topic-Based Approach

In a topic-based approach, study in each science class is organized around topics that can profitably be investigated across the domains of science. Such topics are rich and varied; they include such things as light, atomic energy, oceanography, a local wetland, water quality, and acid rain. By coordinating study across the physical sciences, life sciences, and earth and space sciences, teachers weave together the fundamental understandings common to them all. Learning Standards derive from each particular domain, and the curriculum is structured to help students make connections across the domains.

Examples of Topic-Based Approach

Illustration 1

Light

Eighth grade students are enrolled in a topic-based science course, incorporating the study of light. In physical science, they study reflection, refraction, and absorption of light as well as methods of producing light; when studying life science, they investigate how the cornea of the eye refracts light; and when studying the earth and space sciences, they explore how the moon reflects light from the sun.

Tenth grade students investigate light as it pertains to geometrical optics, image formation, and rudimentary spectroscopy with telescopes in earth and space sciences.

Twelveth graders study the effect of lasers on cellular material in a biology class, e.g., eye surgery; the causes of electron movement to produce light in chemistry or physics class; and the uses of the electromagnetic spectrum and namometer, e.g., red-shift or using lasers to study seismological activity.

Illustration 2

Oceanography

Seventh grade students attend a school district that will integrate science using a topic-based approach. Oceanography is one topic students will study. When students study physical science, they investigate the properties of waves and waves length. When they study life science, they learn about zooplankton and phytoplankton; and when they study earth and space science, students investigate the characteristics of the ocean floor.

In the ninth grade, when students study physical science, they investigate the chemical properties of ocean water. In life science, students explore the flora and fauna in a tidal pool. When studying earth and space science, students investigate the development of tropical storms over warm ocean waters.

In the eleventh grade, students investigate the force of waves as they crash onto the coast, complex ocean food chains and the formation of islands and ocean trenches.

Unifying Concepts Approach

In a unifying concepts approach, science learning is organized directly around the concepts and processes common to all the domains of science. Appropriate unifying concepts, which may be determined by the local school district, might include such ideas as *Patterns and Change; Constancy, Change, and Measurement; Interaction and System; Evidence, Models, and Explanation; or Evolution and Equilibrium.* Learning Standards from particular domains, that illustrate the unifying concept are grouped together and the curriculum structured on that basis.

Examples of Unifying Concepts Approach

Illustration 1

Pattern and Change

An elementary program organizes instruction around the concept of "Patterns and Change," focusing on seasonal changes. Over the course of the school year, the children record changes they observe in deciduous trees; look for animal tracks and observe how animals gather food; study changes in plant growth; keep track of the sun's position in the sky; and look for patterns in sunrise and sunset times.

Illustration 2

Constancy, Change and Measurement

Change as a unifying concept is studied in each and all the domains of science. The change in energy from potential to kinetic provides the focus in the physicalsciences; the metamorphosis of insects and the life cycles of plants serve as subjects for the life sciences; the forces involved in rock formation are studied in the earth and space sciences. The study of change in each domain promotes awareness of patterns and relations in the natural world.

More examples of how studies might cross the domains are found in the preceding Inquiry Strand and throughout the other three strands.

Any approach to cross-domain learning will require a team effort from faculty. Where domain-based classes are retained, teachers will need to plan collaboratively to ensure that the topics or unifying concepts are well articulated across their classes. If the curriculum is organized to address multiple domains within a particular course, team planning by subject matter specialists will be necessary and a team teaching configuration may well be an effective mechanism for instruction. Following are three examples of ways high school staff have begun crossing the domains of science in their schools.

Getting Started I: Crossing the Domains of Science with the Help of Communications Technology

Boat design, navigation, and the principles of sailing are central topics in the physics learning that happens in the Sailing through Physics program at Hull Jr./Sr. High School. It is a program that allows students in Grades 8 through 12 to witness and understand the physical laws of nature in action.

To be sure, our location on a peninsula in Boston Harbor, the enthusiastic local support of local maritime professionals, and our school's commitment to environmental projects all provided the context for launching this innovation. But much more was in the offing.

In order to begin, we needed to draw on each other's expertise in the fields of earth and space science, physics, chemistry, and geography. Since we were all trained in our specific domains, and had spent years teaching our separate subjects, it took us a while to discover each other's interests and talents. But as we sought out the information we needed to make the project work, we began to see how our separate fields fit together and sometimes overlapped. We discovered that the topic of weather offered us the opportunity to bring the science domains together.

As we got further along, each of us selected a resource to explore for its usefulness to our project. These resources were not domain based; rather, they included such things as computer technology, literature, and community. As we shared our findings with other members of the project team, we found ourselves helping each other with new ideas and becoming more aware of how and why the domains overlap.

Ms. Marcks wrote: "As I used my newly acquired computer skills to search the Internet, I found much information about weather. I shared this information with the earth and space science teacher and the physical science teacher, and together we organized a large-scale plan for collecting weather data and disseminating it to other schools. The data we collected included readings of temperature, barometric pressure, wind velocity, and precipitation. The students soon learned about instruments, units of measure, and the need for precision and accuracy. They now understand weather well enough to make predictions that they can broadcast over the school's public address system!

The teachers loved this program and the students engulfed it. It's real science, and I suspect we are all learning in ways that will stay with us for a very long time to come."

Getting Started II: Looking at What We Have -- Chelmsford Teachers Focus on Frameworks

In Chelmsford, thirteen volunteer teachers representing grades 6-12 have made a three-year commitment to work together to revise our science curriculum. We see the revision as an ongoing process that will occur in three phases: review of existing science programs and targeting areas for change (Year 1, now in progress); first revisions and pilot programs, along with teacher training (Year 2); full implementation (Year 3). Periodic assessment of our progress and the success of the changes are an essential part of our three-year plan.

We began by meeting after school to discuss the draft Science and Technology chapter and the Common Chapters. Recognizing that the frameworks are guidelines, not mandates, we evaluated our 6-8 and 9-12 science programs in terms of the learning environments, teaching styles, and methods of assessment. We found that many of the framework recommendations were already in place, and we then identified areas for change. In a full release day session, we compared our curriculum offerings to the proposed Learning Standards for each grade span. It was obvious that our weakest areas were ecology and environmental science.

During a four-day summer workshop, we realized that many parts of our existing science programs could be taught from an environmental point of view. We chose "Cycles" as a trial theme or "thread" that could easily be picked up and pulled through our 6-12 curriculum. Content overlap from year to year would allow us to reinforce and expand our students' knowledge. The "necessary change" became more manageable when each grade level teacher was responsible for a smaller part of it. Students at each grade level would be asked to solve an open-ended problem focusing on ecological or environmental cycles to tie each year's activities together.

Grade-level teams of 2-3 teachers then developed new activities (or revised existing ones) focusing on cycles. We wrote objectives, identified resources, and recommended use of appropriate technologies. As we met to evaluate each other's work, we realized that we couldn't discuss cycles in some contexts without working with the concept of energy. An energy thread will be the next one that is woven into our curriculum.

As a ninth grade physical science teacher, I am looking forward to studying acids with my students while they try to identify points in the water cycle where rain becomes acidic. We will collect acid rain data in Chelmsford and add it via E-mail to a national study called Students Watching Over Planet Earth. We'll go out to the student parking lot and bubble car exhaust through distilled water to determine its effect on pH. We may even take to the roof, where we can gather data on the speeds of cars as they travel through town on Route 3 (replacing the current "speed lab" that involves rolling a marble down a ruler). Just how much traffic is there on a given day and what effect might it have on the acidity of the rain in Chelmsford? I don't know, yet, but I do know that the curriculum will be more fun, more relevant to the students, and more responsive to the frameworks.

Getting Started III. Time and the School Day: Commitment to Real Change in One High School's Science Program

Dennis-Yarmouth Regional High School is making major changes in its science program in a curriculum overhaul that is expected to take two years to complete. As the program develops, emphasis will shift from traditional content based courses to a new emphasis on process, inquiry, cross-domain subject matter and interdisciplinary connections to mathematics and technology.

Key to the change is a reorganization of instructional time. All science classes will meet in ninety minute sessions, and while ninth graders will continue to take a year long course, courses for grades ten through twelve will be organized by semester.

The new curriculum is organized into three courses of study: Environmental Science (Grade 9), Human Anatomy and Physiology (Grade 10) and Matter and Energy (Grade 11 or 12). All three courses will integrate topics traditionally taught separately, e.g. optics, light, acid and base chemistry. Content strands woven through the three year core curriculum will help students understand key scientific principles, while a greater than usual emphasis on inquiry skills will help them to ask good questions.

Dennis-Yarmouth will continue to offer Advanced Placement courses in biology and physics to eleventh and twelfth graders. Juniors and seniors may also elect to take a "Research in Science" course. In these classes, a maximum of five students will work together doing original scientific research on a topic chosen by an instructor. These intensive classes in hands-on science will each meet 90 minutes a day for one semester. In time, all science teachers will teach one "Research in Science" course each year.

Throughout the curriculum, collaboration with the math department will stress the use of graphing calculators and data acquiring probes.

Strand 2: DOMAINS OF SCIENCE

Physical Sciences

The physical sciences study energy and matter; they include both physics and chemistry. In the physical sciences, students learn about the composition, structure, properties, and reactions of matter as well as the relationships that exist between matter and energy.

Students build understandings in the physical sciences through repeated and increasingly sophisticated hands-on experiences with materials, substances, forces and motion, and energy transformations. The links between these concrete experiences and more abstract knowledge are forged gradually. Over the course of their schooling, students develop more inclusive and generalizable explanations about the workings of the physical and chemical world.

Tools play a key role in the physical sciences, helping students to detect physical phenomena that are beyond the range of their senses. Successful use of instruments and computer-based technologies helps students engage with physical phenomena in ways that support greater conceptual understanding.

The Physical Science Learning Standards for grades PreK through four fall under the following headings: *Properties of matter, Position and motion of objects, Forms of energy -- light, heat, electricity and magnetism.* All students start to build knowledge about the physical world as they explore, examine, and manipulate common objects in their environment. Their growing repertoire of actions and thoughts about ordinary things allows them to make the intellectual connections necessary for understanding how the physical world works (Duckworth, 1987). Students note similarities and differences by observing, manipulating and classifying objects. Their descriptions of the physical world are mostly qualitative in this grade span.

Like all students, young children need opportunities to represent their ideas about the physical world in a variety of ways including language, pictures, graphs, and age-appropriate mathematical statements. The more abstract ideas in physical science such as force, gravity, and atomic structure are less useful at this stage than they will be later on.

The Physical Science Learning Standards for grades five through eight fall under the following headings: *Properties of matter, Particulate model of matter, Motion and changes in motion, and Transformations of 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, real-world experiences to help them develop concepts associated with force, gravity, and molecular structure. As they move through the grade span, students gain a more sophisticated idea of what scientific investigation entails. As they learn to make accurate measurements using a variety of instruments, their experiments become more quantitative. With their increased cognitive abilities, middle school students also begin to move beyond physical examinations to model making, representing changes in matter, substances, and energy at the molecular level. These models will take many forms, including physical, illustrated, mathematical, and verbal models.

The Physical Science Learning Standards for the grades nine through ten fall under the following headings: *Structure of matter, Interaction of substances, Forces and motion, and Conservation and transformation of energy*. By the end of grade ten, students can understand the evidence that underlies more complex models of the physical sciences, including the electronic and nuclear structure of the atom, vector quantities, and transformations of energy. Graphical representations and the gradual introduction of functions and limits introduce students to well-defined laws and principles of physical science. At this stage, students are able to make formal statements of principles in the physical sciences, and understand their implications. These principles have important connections to the life and earth sciences which can be explored in the study of such inter-domain topics as the cycling of matter in ecosystems.

Physical science study during grades eleven and twelve fall under the same headings as for grades nine through ten. Physical Science study in these two last years builds upon, expands, and applies the physical science knowledge developed during earlier years. At this level, students develop understanding and expertise by relating classroom learning in the physical sciences to community and/or worksite experience or by studying key topics in the physical sciences in depth.

Students in the upper grades should have the opportunity to choose from a variety of physical science programs, and each course of study should be designed around a strong intellectual core. Students may then choose courses best suited to their own interests and career goals. Options for study might include: *Advanced Placement Physics and Chemistry; Advanced Topics in Electromagnetism; Advanced Topics in Energy Conservation; Applying Principles of Technology/Physics Seminar; Environmental Engineering and Technology; Internship in Energy Conservation; Internship in Pharmacology.*

The following learning standards often use processes of inquiry to illustrate the ways in which content understandings in the Domains might be explored. However, the applications chosen as illustrations do not imply that these are the only or best way that content understandings can be addressed. Many standards are followed by an example of student learning.

Grades PreK-4 Learning Standards and Examples of Student Learning

Properties of Matter

- Identify the observable properties of objects such as size, weight, shape, and color. For example, in their explorations students use the properties of various objects to describe, group, or classify them.
- Give evidence that objects are made up of different materials. Show that properties are useful in describing, grouping and classifying materials. For example, students use properties such as color, texture, magnetic characteristics, and different behaviors when heated or cooled in order to compare and measure the attributes of these materials.
- Represent an understanding that materials can exist in different states, including solid, liquid, and gaseous, and identify different characteristic properties of materials in each state.
- Show and describe how change in a material may be either physical, such as changes in state or appearance, or chemical, such as changes in composition. Students show ways in which some properties of a material may change and others stay the same when a material experiences some external change.

Position and Motion of Objects

- Describe the motion of an object in terms of change in position relative to another object or the background.
- Experience and describe how an object's motion can be changed through the action of a push or pull on the object.
- Demonstrate that sound is produced by vibrating objects. Students investigate ways of altering properties of sound such as pitch and loudness by changing the characteristics of its source.

Forms of Energy: Light, Heat, Electricity, and Magnetism

- Represent an understanding that the Sun supplies heat and light to the Earth.
- Manipulate a variety of objects in a beam of light in order to explore conditions in which different objects cast shadows, bend, or transmit light.
- Demonstrate that things that give off light may also give off heat. For example, students explore and describe ways in which heat is produced by mechanical and elctrical machines, and friction.
- Investigate situations in which changes in matter also give off energy as light, heat (or sound). For example, students experience the sound produced by a vibrating object. They describe the cause and effect relationship between a sound and the vibration of its source.
- Use qualitative or quantitative measurement to investigate the concept what warmer things put with cooler ones lose heat and the cool ones gain heat until they are all at the same temperature
- Explore and describe how heat travels more quickly through some materials than others.
- Provide evidence that a magnet pulls on all things made of iron and either pushes or pulls on other magnets. Students discover how magnetism operates over short distances, and how a magnet's pull diminishes rapidly as it moves away from an iron object.
- Demonstrate how materials that have been electrically charged may either push or pull other charged materials.
- Investigate and describe how light, sound, heat, and sparks can be produced in electrical circuits using batteries as an energy source.

Learning Looks Like This . . .

Let it Melt

A first grade teacher has noticed that many of her children newly arrived from Santo Domingo are fascinated by this winter's first snow. When two boys bring in their snowballs after lunch recess, she seizes the opportunity to involve them in an informal experiment regarding changes of state. To help organize their thinking she asks them *"What do you think will happen if you leave this snowball indoors?" and then "Why do you think that will happen?"*

After the boys have told her their ideas, she asks them to help discover what will happen. They place their snowballs in jars, and then mark off the height of their solid snow on the jar's edge with a black marker. She then asks the boys to imagine the snowballs in their melted state, and indicate with a red marker the height on the jar where they each think the melted snow would be. One boy places a mark higher on the jar's edge, the other marks the same height as the snowball. She hopes for an interesting discussion tomorrow when the boys will be able to observe the melted snow in the jars, and think about whether their hunches were borne out and why. She also expects that refreezing the melted snow in the school freezer the next night will stimulate some interesting discussions about the differences between snow and ice.

Grades 5-8 Learning Standards & Examples of Student Learning

Properties of Matter

- Identify properties that allow materials to be distinguished from one another and often make them well suited to specific purposes. For example, compare and measure different materials in terms of their characteristic properties such as density, texture, color.
- Identify and classify elements and compounds with similar properties, such as metals, metalloids and non-metals; acids and bases; combustibles and non-combustibles
- Present evidence that a chemical change involves the transformation of one or more
- substances into new substances with different characteristic properties. Give examples that such changes are usually accompanied by the release of or absorption of various types of energy, especially radiant energy such as heat or light.
- Explore and describe that the mass of a closed system is conserved. For example, if a wet nail is put in a jar and the lid closed, the nail will rust (oxidize) and increase in mass but the total mass in the contents of the jar will not.
- Measure and predict changes in the pressure, temperature, or volume of a gas sample when changes occur in either of the other two properties.

Particulate Model of Matter

- Describe a particulate model for matter that accounts for the observed properties ofsubstances.
- Recognize and explain how experimental evidence supports the idea that matter can be viewed as composed of very small particles, (such as atoms, molecules and ions), which are in constant motion. Illustrate understanding that particles in solids are close together and not moved about easily; particles in liquids are about as close together and move about more easily; and particles in gases are quite far apart and move about freely.

- Provide evidence that shows how the conservation of mass is consistent with the particulate model that describes changes in substances as the result of the rearrangement of the component particles.

Motions and Changes in Motion

- Show and describe how forces acting on objects as pushes or pulls can either reinforce or oppose each other.
- Demonstrate that all forces have magnitude and direction. Create situations to model how forces acting in the same direction reinforce each other and forces acting in different directions may detract or cancel each other.
- Describe and represent an object's motion graphically in terms of direction, speed, velocity, and [or] position versus time. Also describe these quantities verbally and mathematically.

Transformations of Energy

- Represent an understanding that energy cannot be created or destroyed but exists in different interchangeable forms, such as light, heat, chemical, electrical, and mechanical.
- Present evidence that heat energy moves in predictable ways, flowing from warmer objects to cooler ones until both objects are at the same temperature. Predict and use tools to measure this movement.
- Illustrate an understanding that energy comes to the Earth as electromagnetic radiation in a range of wavelengths, such as light, infrared, ultraviolet, microwaves, and radio waves. Explain ways in which the amount of each type of radiation reaching the surface of the Earth depends on the absorption properties of the atmosphere.
- Investigate and describe an understanding of visible electromagnetic radiation, which we generally call light, with reference to qualities such as color and brightness. Illustrate understanding that light has direction associated with it, and can be absorbed, scattered, reflected or transmitted by intervening matter. Demonstrate and explain refraction as the process by which light's direction can be changed by passing from one medium to another.
- Explain ways that energy can be changed from one form to another. For example, heat and light are involved in physical or chemical changes and at times may be accompanied by sound.
- Demonstrate principles of electrical circuits. Use wires, batteries, bulbs and instrumentation to measure and analyze electrical energy resistance, current and power. Use electric currents to produce electromagnetic coils of wire, and, conversely, use a moving magnet to generate a current in a circuit.

Learning Looks Like This . . .

How Loud is Loud?

In a sixth grade classroom, students' interest in noise and sound levels was sparked by the comments of a hearing-impaired classmate. Students wanted to know where the transmission of vibrations stopped in the ear and in what ways this prevented her from hearing. They also had many questions about perceived loudness levels, and why, for example, their favorite music was considered loud by their parents but seemed fine to them.

Ms. Collins, their teacher, guided their inquiry by first helping them to generate a list of everyday sounds in their lives, and to consider which they thought of as loud. They explored the decibel levels in the *locker room, the school lunchroom, the study hall, and noted the differences in materials, e.g. how the metal lockers, and linoleum floors of the gym space contrasted to the carpeted floors and padded chairs of the library. Soon the question of how sound is transmitted became important. They discovered that sound travels through solids, and through the air, and were sent home with the challenge of testing whether sound travels through water. Ms. Collins devised a way for students to see how the transmission of vibrations resulted in sound. She set up a slinky attached from one chair to another across the classroom and requested students tap it, noticing the way in which the vibration traveled transversely, without the coil of the slinky substantially changing position. Ms. Collins helped her students pursue their questions concerning why a decibel level is considered loud by some people, and not loud by others. Students interviewed their parents concerning their perceptions of loudness levels at home, and began to organize their results and generate new questions.*

Grades 9-10 Learning Standards & Examples of Student Learning

Structure of Matter

- Explore and describe how matter is made up of elements, compounds, and numerous mixtures of these two kinds of substances. Students might design and conduct investigations that explore ways to demonstrate this.
- Demonstrate through the use of manipulatives that atoms interact with one another by transferring or sharing electrons that are furthest from the nucleus.
- Represent an understanding that compounds form when atoms of two or more elements bond. Give examples that chemical bonds form when atoms share or transfer electrons.
- Group elements and compounds into classes, based on similarities in their structures and resulting properties.
- Describe an understanding that nuclear changes often result in the emission of high-energy electromagnetic radiation and particles, and present evidence on ways that this has physical repercussions on other materials.
- Illustrate an understanding that energy is released in certain nuclear reactions and chemical reactions can be controlled and put to use, or released suddenly and destructively in explosions, fire, or high-energy chemical events. Provide examples of situations in which this has occurred in recent history.

Interaction of Substances (Chemical/Physical Changes)

- Present evidence that solubility of substances may vary with temperature and with the natures of the solute and the solvent. Plan and conduct investigations in which the temperature, solute or solvent is varied while the other variables are kept constant.
- Suggest how balanced electrical forces between the charges of the protons and electrons are responsible for the stability of substances. Students might design an investigation to show how chemical interactions or physical changes occur when these forces are altered.
- Explain chemical changes in terms of rearrangements of atoms or molecules, which are made possible by the breaking and forming of chemical bonds.
- Summarize chemical reactions by symbolic or word equations that specify the reactants and products involved.
- Illustrate ways in which the periodic table is useful in predicting the chemical and physical

properties of known elements and those yet to be discovered.

Forces and Motion

- Demonstrate that all forces are vector quantities, having both magnitude and direction. Explore ways in which forces acting in the same direction reinforce each other. Also explore ways in which forces acting in different directions may detract from or cancel each other.
- Represent an understanding that if an object exerts a force on a second object, then the second object exerts an equal and opposite force on the first object.
- Describe and represent changes in motion or momentum in terms of being caused by forces. Students might set up demonstrations that show the result of forces on motion, e.g. gravity, friction or electrical.

Conservation and Transmission of Energy

- Explore and explain how the total amount of mass and energy remains constant in any closed system. Present evidence to show that Earth is a nearly closed system with respect to matter, but not to energy. Describe the implications of this idea for life and earth sciences. Be aware of inputs of matter.
- Describe the nature of waves, such as electromagnetic waves or sound waves, in terms of wave length, amplitude, frequency, and characteristic speed. Present evidence that waves can be used to transmit signals or energy without the transport of matter.
- Design and conduct an investigation that explores how electromagnetic waves, unlike sound waves, can be transmitted through a vacuum.
- Demonstrate that the same concepts of energy, matter and their interaction apply both to biological and physical systems on Earth and in the observable Universe.

Learning Looks Like This . . .

Modeling Scientists

Science projects can give students a taste of what scientists do each day and provide them with lifelong learning skills. Mr. Ryan of Medford High School and the Massachusetts State Science Fair writes about how doing a science fair project is integrated with the regular curriculum, therefore the concepts and skills learned in class can be applied to student projects.

One of the hardest things for students to decide upon is a question or topic. I tell them they need only to look around and ask "why" or "how" about the world in which we live. These questions are the starting points for science explorations. Rather than leading to a definite end, these often yield more unanswered questions. What is important is that students model real scientists as they probe the unknown and discover bits and pieces along the way. At the high school level, students are ready to do science projects that are truly experimental. Whatever phenomena they choose to investigate,I expect them to follow the strategies and procedures used by scientists. To help my students develop a scientific way knowing, I expect my students to:

1. Keep a journal, detailing their thoughts and activities, i.e., library research, discussions with others, notes about making or collecting the necessary materials and apparatus, and records of data from their experimental trials.
2. Write accurate and concise lab reports during the course of their work, and organize and write a

full project report at the end of the year. The report often includes data tables or graphs that accurately and concisely communicate the desired information. Communicating findings and their meaning in written form is important scientific work.

3. Present their findings in a mini-science fair. Like real scientists at a convention, my students display their findings and talk to other students in class about what they learned.

Some examples of projects have included: "How do different soaps and detergents compare with regard to emulsifying fats and oils?" and "What are the different geometric shapes that various substances grow in?"

Learning Looks Like This . . .

Olympics, Fairs, and Olympiads

An effective strategy for engaging many students in the study of science is through playful, challenging, and technologically competitive projects. As a balance to the rigorous nature of science competitions, these can be organized through in-class mechanisms such as lab periods, after school or assembly type competitions, or through outside organized interscholastic events such as Physics Olympics and Science Olympiads.

For example, in a recent Physics Olympic competition, students were challenged to position a laser in front of a semi-circular cell filled with a fluid (water, glycerin, etc.) so that the refracted ray will intersect a point on the wall 2-3 meters away. The actual target is determined by drawing a card just prior to the challenge. Students are given a semi-circular cell filled with an unknown liquid, pins, polar graph paper, and a light source. They must find the index of refraction for the liquid, and based on their data, orient the laser to refract a ray that will intersect the target.

Teachers' experiences with Physics Olympics have proven time and again that when exploration, collaboration and engineering design projects are combined with fun, not only do students develop motivation to work on science overtime, but it tends to draw out diverse groups which might be more inhibited in a normal classroom setting. Girls and boys are eager to participate. Hands-on, do-it-yourself types are likely to team up with a mathematical theoretician, sensing that their diverse skills will produce a more rounded and successful team.

Grades 11-12 Learning Standards & Examples of Student Learning

Structure of Matter

- Represent an understanding that an atom consists of a positively-charge nucleus (composed of protons and neutrons) surrounded by one or more negatively-charged electrons. Create and use models to study the structure of atoms.
- Illustrate an understanding that atoms of the same element have the same number of protons and electrons but may exist in forms (isotopes) that differ in the number of neutrons.
- Predict the properties of a compound using knowledge about the structure of its smallest units (either molecules or ionic crystals).
- Represent pure substances by using formulas or three dimensional models that show the number, types and/or relative position of atoms that make up the substance.

- Illustrate an understanding that forces among particles in a nucleus are extremely strong and act at very small distances. Identify specific examples of how large quantities of energy are associated with nuclear changes.
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Interaction of Substances (Chemical/Physical Changes)

- Investigate situations in which physical and chemical changes do not proceed to completion, but reach a state of equilibrium with the rate of change in one direction being equal to the rate of change back in the other direction.
- Classify chemical reactions into general types based on the nature of the reactants and changes involved such as acid/base, oxidation-reduction, precipitation, polymerization.
- Collect and present evidence demonstrating that the rate of reaction can be increased by adding a suitable catalyst. Present evidence that the rate is also affected by changes in temperature, and by surface area, or concentration of the reactants. Describe the implications of these three points for living systems.
- Explore and illustrate an understanding that the amount of energy involved in changes of state of molecular liquids and solids is determined by the type of attractive forces between the molecules.
- Investigate and describe an understanding that the amount of energy involved in chemical changes is determined by the differences in stability of the bonds within the molecules.

Forces and Motion

- Explore and illustrate situations that show how the position and motion of an object are judged relative to a particular frame of reference. Examine evidence that an object at rest tends to stay at rest unless acted upon by some outside force. Also examine evidence that an object in uniform motion remains in this state of motion with constant momentum unless acted upon by an unbalanced force.
- Illustrate and describe an understanding that motion can take place in two or three dimensions. Describe an object's motion in terms of velocity or acceleration, and represent motion in various ways, including distance-time, and speed-time graphs, as well as by mathematical equations, and vectors.
- Explore and describe an understanding that acceleration is the rate of change of velocity, where the change may be in magnitude or direction. Students might represent the relationship of force, acceleration and mass using physical, conceptual, and mathematical models.
- Demonstrate an understanding that constant motion in a circle requires a force to maintain it, because velocity is constantly changing.

Conservation and Transmission of Energy

- Investigate and describe the idea that the total quantity of energy in a closed system remains constant in any chemical or physical change, although its usefulness to prompt further change is reduced through each process as randomness increases. Describe the consequences of this for living systems.
- Conduct investigations to gain evidence that interactions of matter with electromagnetic radiation, electricity, or heat can produce useful evidence regarding the structure and composition of matter.
- Design and conduct investigations which illustrate that the loss or gain of heat energy by a sample of matter is related to a temperature change, which depends on the sample's mass, the nature of its

material, and the environment in which it is placed.

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Learning Looks Like This . . .

Physics in Action

Students at Cambridge Rindge and Latin School can take a course in their junior or senior years that applies physical science knowledge to technology through study of the construction of equipment designed for science experiments and projects. The focus is on measurement, motion in one and two dimensions, navigation by map and compass, simple machines, buildings and structures, force, work and energy. Students learn fundamental principles of physics and mechanical engineering. This course is titled Physics and Engineering: Craft of Science, and it is offered by the Rindge School of Technical Arts, for the Industrial Technology and Engineering Pathway and is open to upperclass students.

Strand 2: DOMAINS OF SCIENCE

Life Sciences

The life sciences study living organisms and life processes from the cellular level to the biosphere. Students investigate individual organisms and they ask questions about relationships, including how organisms interact among themselves, how they relate to their environments, and how life forms behave over time. In the life sciences, students also learn how the human body works and how humans interact with the environment. The life sciences also address the unity and continuity of life, as well as change and diversity.

The Life Sciences Learning Standards for grade span PreK through four fall under four headings: *Characteristics of organisms, Adaptation of organisms, Heredity, and organisms and environments.* As Piaget noted, young children tend to describe as "alive" anything that moves. Over time, students come to refine this intuitive understanding to include such behaviors as eating, breathing, and reproducing. They also start to think about how organisms maintain life and how they interact with the living and non-living world around them. Through experience and observation, they begin to see how familiar organisms show diversity and variability. As they build these kinds of understandings through direct experience with the living world, young children are introduced to the power of empirical evidence. Learning takes time and many revisits, because young children's observations are often influenced by prior beliefs and experiences.

The Life Science Learning Standards for grades five through eight fall under the following headings: *Characteristics of organisms; Diversity and adaptation of organisms; Heredity, reproduction and development; and Ecosystems and organisms.* Students in this grade span study a broader range of organisms and engage in experimentation and field study. Now able to manipulate a light microscope, they can observe cells and begin to understand the biochemical foundations of life. Human biology, reproduction, and organ function greatly interest students at this age and are accessible topics during these years. Observable traits may be a focus for heredity study at first, though the genetic basis of heredity will not be well understood until late in the grade span. Adaptation is also understood in very concrete terms at this time.

As they learn to analyze patterns with increasing complexity, students will start looking at variation and diversity in more sophisticated ways. Their classificatory systems become more complex and begin to conform to those used in the scientific community. At this level, students begin to study ecosystems and to appreciate the interdependence of all organisms; this understanding lays the foundation for the study of evolution.

Learning Standards in grades nine and ten fall under four categories: *Characteristics of organisms, Evolution of life, Principles of heredity, and Matter and energy in ecosystems.* In these two challenging years of study, students engage with four of the big ideas of the life sciences: the physical and chemical nature of life processes; the molecular basis of heredity; evolution; and the flow of matter and energy in biological systems. Besides underpinning the life sciences, these big ideas are fundamental to understanding many of the social and environmental issues of our time. If students are to adopt informed positions on these issues and behave as responsible citizens, as the Massachusetts Common Core of Learning urges, they must first understand the underlying science.

Life science study during grades eleven and twelve falls under the same headings as for grades nine through ten. Life sciences study in these last two years builds upon, expands, and applies knowledge developed during earlier years. At this level, students develop understanding and expertise by relating classroom learning in the life sciences to community and/or worksite experience or by studying key topics in the life sciences in depth.

Students in the upper grades should have the opportunity to choose from a variety of life sciences programs, and each course of study should be designed around a strong intellectual core. Students may then choose courses best suited to their own interests and career goals. Options for study might include: *Advanced Placement Biology; Advanced Topics in Human Anatomy and Physiology; Applying Principles of Technology/ Biology Seminar; Bioengineering Seminar; Environmental Engineering and Technology; Internships in Biotechnology; Internships in Health Science; Internship in Hospital.*

The following learning standards often use processes of inquiry to illustrate the ways in which content understandings in the Domains might be explored. However, the applications chosen as illustrations do not imply that these are the only or best way that content understandings can be addressed. Many standards are followed by an example of student learning.

Grades PreK-4 Learning Standards and Examples of Student Learning

Characteristics of Organisms

- Explore and describe that plants and animals are living things and have characteristics that differentiate them from non-living things.
- Demonstrate an understanding that plants and animals go through predictable life cycles. These cycles differ from species to species, but all include growth, development, reproduction, and death.
- Observe and describe that plants and animals have different structures which serve different functions in growth, survival, and reproduction. These contribute to the well-being of the whole organism, and to the success of its offspring.
- Demonstrate awareness that there are millions of kinds of living things on earth, and that the

number of species is not known. Classify living things on the basis of similarity in appearance and behavior.

Diversity and Adaptation of Organisms

- Give examples of how different plants and animals have features that help them thrive in different kinds of places. Recognize that these features may be external, or internal (such as warm- or cold-bloodedness), or behavioral.
- Identify some kinds of organisms that once lived on earth and that have completely disappeared. Describe ways in which some organisms that lived long ago are similar to existing organisms, but some are quite different.
- Observe and illustrate ways that individuals of the same kind differ in some of their characteristics, and that sometimes the differences give individuals an advantage in surviving and reproducing.
- Compare fossils to one another and to living organisms according to their similarities and differences.

Heredity

- Provide examples of variations as well as similarities among individuals of the same species. Recognize that although it is hard for us to see this, it is true of all kinds of organisms.
- Observe and describe that some of the variations within a species are acquired during the individual's lifetime (such as an athlete's muscles, or the ability to play the piano); some were inherited from the individual's parents (such as eye color); some start with inherited tendencies, which develop in individual ways owing to the conditions of the individual's life (such as height and foot-size).
- Identify ways that offspring resemble their parents, but are not identical to them. Realize that in every group of organisms, there is variation in every characteristic.

Organisms and Environments

- Provide evidence that all organisms use some basic chemical building blocks, including water and oxygen. Observe that each kind of organism has special living requirements, and each has its own way to get the energy and nutrients it needs. Observe that green plants can make their own food from sunlight; animals consume plants or other organisms for their food.
- Explore and illustrate an understanding that decomposers, which are single-celled organisms and fungi, break down dead plants and animals for food.
- Provide examples of living organisms meeting their needs by interacting with living and non-living parts of the environment in which they live. Observe that species are dependent on each other to maintain life. Examine ways in which the different features of each species enable it to live and reproduce in a particular environment (habitat).
- Observe and demonstrate ways that all organisms effect change in the environment where they live. Recognize that some of these changes are detrimental to themselves and other organisms, whereas others are beneficial. Observe ways that changes in environmental factors, such as humidity, temperature, and light, also affect the organisms in an environment.

Learning Looks Like This . . .

Are You Me?

In order to help her students understand the fascinating process of growth and change, Ms. Allard from Fall River designed a science project for her third graders that focused on the developmental stages of animals. Beginning with the children's own world, she encouraged them to bring in pictures of themselves both as infants and now. Identifying similarities and discussing differences in their two pictures formed the basis for her students thinking about change. She was amazed at the ways in which children were able to recognize each other from their baby pictures, because they noticed details, like the shape of the head, the thrust of a jaw and other physical characteristic details which were not the same ones contained in her own observational repertoire. Becoming astute observers, and developing facility in documenting their observations were critical skills for their study of change. When she brought a clump of frog eggs in to class in the spring, students flexed their observational skills to document changes from egg to tadpole to frog.

Grades 5-8 Learning Standards and Examples of Student Learning

Characteristics of Organisms

- Identify the cell as the basic unit of life and the smallest unit that can reproduce itself. Give examples of single and multi-cellular organisms.
- Explore and describe an understanding that plants, animals, fungi, and various types of microorganisms are major categories of living organisms. Each category includes many different species. Note that these categories are subject to change. Life does not always fit into neat categories (e.g., are viruses alive?)
- Observe and explain that in single cells there are common features that all cells have as well as differences that determine their function. Compare the features of plant and animal cells noting similarities and differences.
- Investigate and illustrate evidence that cell replication results not only in the multiplication of individual cells, but also in the growth and repair of multi-cellular organisms.
- Present data to illustrate that all organisms, whether single or multi-cellular, exhibit the same life processes, including growth, reproduction and the exchange of materials and energy with their environments.
- Describe ways that cells can differ in multi-cellular organisms, assuming different appearances and carrying out specialized functions.
- Investigate and explain that complex multi-cellular organisms are interacting systems of cells, tissues, and organs that fulfill life processes through mechanical, electrical, and chemical means, including procuring or manufacturing food, and breathing and respiration.

Diversity and Adaptation of Organisms

- Explain situations in which short-term changes in available food, moisture, or temperature of an ecosystem may result in a change in the number of organisms in a population or in the average size of individual organisms or in the behavior of individuals in a population. Explore through models and evidence ways in which long term changes may result in the elimination of a population or the introduction of new populations.

- Explore and illustrate that in both the short and long term (millions of years), changes in the environment have resulted in qualitative and quantitative changes in the species of plants and animals that inhabit the Earth.

Heredity, Reproduction and Development

- Explain the importance of reproduction to the survival of the species. Students compare and contrast sexual and asexual (e.g., yeast) reproduction.
- Investigate and describe processes by which organisms that have two parents receive a full set of genetic instructions by way of the parents' reproduction cells specifying individual traits from each parent. Offspring exhibit traits from each parent.
- Illustrate an understanding that sorting and recombining of the genetic material of parents during reproduction produce the potential for variation among offspring.
- Examine evidence and describe that there are minor differences among individuals from the same population or among individuals of the same species. Explore ways in which some differences are acquired by the individual and affect only that individual, while other differences can be passed on to the individual's offspring.

Ecosystems and Organisms

- Present evidence that species depend on one another. Describe ways in which interactions of organisms with each other and non-living parts of their environments result in the flow of energy and matter throughout the system.
- Explore and illustrate how energy is supplied to an ecosystem primarily in the form of sunlight. Examine evidence that plants convert light energy into stored energy which the plant, in turn, uses to carry out its life processes. Describe how this serves as the beginning of the food chain for all animals.
- Observe and illustrate the variety of ways in which plants, animals, fungi, and microorganisms interact. Represent how matter is cycled and recycled through these interactions, and energy flows through ecosystems.
- Classify organisms according to the function they serve in a food chain (any single organism can serve each of these functions): production of food, consumption of food, or decomposition of organic matter.

Learning Looks Like This . . .

The Return of the Osprey

Children in Ms. Le Boeuf's fifth grade class are involved in investigating why the osprey are returning to the Buzzards Bay area after declining in population for over thirty years.

Field study, including observing birds in the urban area around their school and on the beach, led them to inquire about the changes in the bird population during the last several decades. Study of the relationship between environmental factors such as air, water, and chemical pollution and the concentration of osprey in their area helped them to realize that certain aspects of the environment can be hazardous to certain species under certain conditions (the sort of conditional thinking so important to doing real science!) Their interest widened to include questions concerning how recent environmental laws protect this species. At the end of their project, students designed ideal environments to attract osprey to return to this area.

Grades 9-10 Learning Standards and Examples of Student Learning

Characteristics of Organisms

- Examine evidence and demonstate that many molecular aspects of life processes of multi-cellular organisms occur in cells.
- Investigate and describe understanding that cells have particular structures that underlie their functions. Students compare the structure and function of various cells.
- Compare and contrast the cell boundaries that control what can enter and leave the cell. Realize that in all but quite primitive cells, a complex network of proteins provides organization and shape. Students might observe bacterial, animal, and plant cells.
- Give evidence that all organic molecules are constructed of four fundamental elements, i.e., carbon, hydrogen, oxygen and nitrogen.

Evolution of Life

- Describe the theory of biological evolution which states that the earth's present-day species are descended from earlier species. Students might experiment with or outline the evolution of a particular organism.
- Describe ways in which genetic variation is preserved or eliminated from a population through natural selection. Students might site examples in which chance alone can result in the persistence of some heritable characteristics that have no survival or reproductive advantage or disadvantage for the organism. Students might examine ways that when an environment changes, the survival value of some inherited characteristics may change.
- Examine and summarize evidence that evolution builds on what already exists, so the more variety there is, the more there can be in the future. But know that evolution does not necessitate long-term progress in some set direction.

Principles of Heredity

- Give evidence that cells are the repositories of biological information.
- Explore and illustrate that chromosomes are the components of cells which convey hereditary information from one cell to its daughter cells and from a parent to its offspring.
- Illustrate an understanding that chromosomes are composed of subunits called genes; each gene encodes the information directing the synthesis of a cell product, usually a protein, and can often be identified with a trait observed in the organism. Create annotated drawings, models or other representations.
- Describe the structure and function of DNA.
- Give evidence that in reproductive processes involving two parents (sexual reproduction), two specialized reproductive cells (gametes), one from each parent, (zygote) which directs the formation of a new organism that has attributes of both parents.
- Discriminate between characteristics that result from the operation of a single gene and some that result from the action of several genes.

Matter and Energy in Ecosystems

- Examine and describe ways in which the conservation of energy law is a powerful tool for the analysis of energy flow in ecosystems.
- Demonstrate an understanding that energy is supplied to ecosystems by sunlight and dissipates as heat. Know that the principle pathway of this dissipation is cellular respiration.
- Illustrate an understanding that plants convert light energy into chemical energy.
- Explore and illustrate why carbon compounds produced by plants (carbohydrates and oils) are the primary source of energy for all animal life. Describe the role of plants as a principal source of nutrients (including amino acids) to consumers and decomposers.

Learning Looks Like This . . .

Leaf Pigmentation Study in Arlington

In Arlington, Mr. Bockler, a tenth grade biology teacher begins with what appears to be a simple question "Why do leaves change color in the fall?" and proves to be a complex investigation in which students grapple with many of the important concepts from other domains of science as well. His goal is to challenge his students to engage in a scientific way of knowing. While initial hypotheses hinge on changes in light, temperature, and the earth's tilt and revolution around the sun, a laboratory exercise concerning leaf pigmentation proves to be the springboard for exploration of many related scientific issues.

The first challenge is to explore alternative explanations for leaf color change.In order to choose the best fit explanation for leaf changes from green to fall colors, students must test specific hypotheses and apply techniques of paper chromatography.

In addition, they consider *"What are the functions of the various pigments in leaves?" "Why are they mostly green in the summer and change in the fall?"* and *"How and why might this differ in tropical regions?"*

They discuss issues of measurement: *"Why are Rf ratios more valuable in comparing results of different groups than in comparing the simple travel distances for each pigment?" "How might other scientists use the chromatography technique in other studies in Biology, for example in food and nutrition studies, in protein chemistry or with DNA studies?"*

Their teacher leads them to questions of evolution and adaptation, *"How are broad-leaved trees and evergreens adapted to seasonal changes?"*

The Biology study is actually a Science study, since physical science content and aspects of earth science are of critical importance to leaf study.

Grades 11-12 Learning Standards and Examples of Student Learning

Characteristics of Organisms

- Demonstrate an understanding that cell membranes often are the sites of chemical syntheses and energy conversions essential to life.
- Demonstrate the relationship between the expression of a gene and a specific enzyme, and the relationship between an enzyme and a chemical reaction.

- Describe the idea that in complex, multi-cellular organisms, cells have specialized functions, communicate with each other, and are mutually dependent. Give examples of the mutual dependency of cells within an organism.
- Explain why biological systems are also physical and chemical systems. Examine evidence that living things operate according to the "laws" of physical science, such as the conservation of matter and energy, and the laws of thermodynamics.

Evolution of Life

- Present evidence that natural selection provides the following mechanism for evolution: Some variation in heritable characteristics exists within every species, some of these characteristics give individuals an advantage over others in surviving and reproducing, and the advantaged offspring, in turn, are more likely than others to survive and reproduce. The proportion of individuals that have advantageous characteristics will increase, if selection pressures do not change.
- Explore and describe molecular evidence that substantiates the anatomical evidence for evolution and provides additional detail about the sequence in which various lines of descent branched off from one another.
- Examine and give evidence that life on earth is thought to have begun as one-celled organisms at least 3.6 billion years ago. Create timelines, graphs, illustrations or other representations to illustrate evolution of life from a single-celled microorganism.

Principles of Heredity

- Illustrate an understanding that many (50,000-100,000) bits of information, or genes, are encoded in human DNA. Describe ways in which the expression of a given trait will depend, to some degree, on the genetic background made up of all other traits.
- Examine and give evidence that in some cases, it is possible for an identical (clone) organism to grow from a single cell or a cluster of cells from the parent organism (asexual reproduction). In the case of asexual reproduction, the offspring is exactly like the parent.
- Demonstrate an understanding that the DNA code based on triplets of four nitrogenous bases is virtually the same for all life forms.
- Represent an understanding that DNA is a chemical substance that can be separated from cells and altered mechanically and chemically in test tubes. Examine evidence that when altered DNA (from the same species) or DNA from another species is introduced into a cell, a new trait may be introduced into the cell's genetic material.
- Describe ways in which fragments of DNA can be analyzed to identify the individual from which the sample of DNA came, diagnose human genetic abnormalities, and study populations.
- Examine and describe evidence that mutations in DNA occur naturally at low rates and take several different forms. Recognize that under certain environmental conditions the probability of mutation increases. Students might track mutated genes in somatic and germ cells of parents and offspring.

Matter and Energy in Ecosystems

- Present evidence that energy flows through an ecosystem from prey to predator in the form of high energy chemical substances.
- Explore and show evidence that energy conversions that take place when animals metabolize carbohydrates and fats from plant or other animal sources are inefficient.

- Present evidence that matter is recycled in ecological systems. Create models that represent the recycling of matter, e.g., water cycle, carbon cycle, nitrogen cycle.
- Identify the mechanisms by which animals and decomposers absorb some of the energy available in their food, but respire the largest proportion. Thus energy gets passed in a diminishing way from sun through plants and consumers; at every step much is lost in respiration. Use these understandings to describe how matter cycles, but energy flows downhill and is lost to the system.

Learning Looks Like This . . .

Fitness Trainers to Medical Doctors

John has been very interested in the study of biology ever since he took his semester - long course in the life sciences during his sophomore year, but he did not do very well in this course. Convinced that science was not in his future, he met with his guidance counselor to plan what to take. His guidance counselor recommended two courses for his junior year: an Anatomy and Physiology course and a course in Health Careers in which students learn about the work and preparation of health professionals, from fitness trainers to medical doctors. Health career exploration included rotation and job shadowing in local hospitals and health care facilities, and after school job placements. John came to realize that he was good at as well as enjoyed this involvement with life science. During his senior year, he undertook a yearlong internship working in a geriatric health care facility.

Strand 2: DOMAINS OF SCIENCE

Earth and Space Sciences

The earth and space sciences study the origin, structure, and physical phenomena of the Earth and the Universe; they include geology, meteorology, oceanography, and astronomy. As they study the earth and space sciences, students learn about the properties of geological materials, the nature and interaction of oceans and atmosphere, earth processes including plate tectonics, changes in the earth's topography over time, and the place of the Earth in the Universe.

Earth and Space Science Learning Standards for grades PreK through four fall under the headings of: *Properties and changes of Earth's materials and Objects in the sky.* Young children come to school aware that the Earth is composed of rocks, soils, water, and living organisms. Early earth science experiences should help them to compare, contrast, and describe these earthly materials and show them the utility of classifying materials according to their properties. Early space science learning will help them to recognize visible objects in the night sky and lead them to think about the characteristic movements of heavenly bodies. Embedding these observations and ideas in a broad exploration of the children's world will help them to see how living organisms (Life Sciences) as well as energy and matter (Physical Sciences) relate to the study of Earth and the Universe.

The **Earth and Space Sciences Learning Standards for grades five through eight** focus on the categories of: *Interactions and Cycles in the Earth System, Earth's History, and Earth and Space.* As students continue to investigate geological materials, their work becomes more quantitative. Attention also shifts from the properties of particular objects to an understanding of the interaction of Geology, astronomy, oceanography and meteorology. Changes in the topography and composition of the earth's crust through time are considered. Students' explorations of Earth's position in space now include the factor of gravity and its effect on the motion of planets, satellites, and other bodies in space.

The **Earth and Space Sciences Learning Standards for grades nine and ten** fall into the following categories: *Matter and Energy in the Earth System, Evolution of the Universe, and Geochemical Processes and Cycles in the Earth System.* Students continue their studies to now 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 learning standards in grades eleven and twelve fall under headings similar to those for grades nine and ten. Earth and Space science study in grades eleven and twelve builds upon, extends, and applies the knowledge developed in earlier years. At this level, students develop understanding and expertise by relating classroom learning in the earth and space sciences to community and/or worksite experience or by studying key topics in earth and space science in depth.

Students in the upper grades should have the opportunities to choose from a variety of earth and space science programs, and each course of study should be designed around a strong intellectual core. Students may then choose courses best suited to their own interests and career goals. Options for study might include: *Advanced Placement Earth and Space Science; Advanced Topics in Applying Principles of Technology/Earth Science Seminar; Ecology; Environmental Engineering and Technology; Internship at an environmental protection agency; Oceanography; Space Sciences Technology Seminar*.

The following learning standards often use processes of inquiry to illustrate the ways in which content understandings in the Domains might be explored. However, the applications chosen as illustrations do not imply that these are the only or best way that content understandings can be addressed. Many standards are followed by an example of student learning.

Grades PreK-4 Learning Standards and Examples of Student Learning

Properties and Changes of Earth's Materials

- Illustrate that the Earth's surface is composed of water, rocks, soils, and living organisms.
- Observe and describe that change is something that happens to earth materials. Investigate conditions in which water can be a liquid, a solid, or a gas.
- Illustrate that some events in nature have a repeating pattern. The weather changes some from day to day, but things such as temperature and precipitation show annual rhythms particular to a geographical area.
- Observe and show that air has properties that can be identified and measured, such as wind speed and direction, temperature, moisture, the occurrence of clouds, and the fall of precipitation. Know that together these properties and events for a particular place and time is called the weather.
- Explore and demonstrate that rocks are made of minerals. Examine evidence that different types of minerals have different physical properties, such as hardness, color, and texture. Use established methods for identifying common minerals.

- Observe and illustrate that rocks come in many sizes and shapes, from boulders to grains of sand and even smaller.
- Show evidence that water flows downhill in streams and rivers, or accumulates in lakes and puddles and seeps into the ground.
- Examine and describe ways in which fossils provide evidence of Earth's history, and show how plants, animals and environments have changed over time.
- Illustrate that the interior of the Earth is hot. Heat flow and movement of material within the Earth moves the continents, causes earthquakes and volcanic eruptions and creates mountains and ocean basins.

Objects in the Sky

- Examine and illustrate that the earth is one of several planets that orbit the sun, and that the Moon orbits around the earth.
- Describe ways in which the Sun, Moon, planets, meteors, clouds and other objects in the sky can be identified by properties such as size, shape, color, brightness, and movement.
- Represent understanding that the Sun provides light and heat.
- Observe and explain why the Sun can be seen only in the daytime, but the Moon can be seen sometimes at night and sometimes during the day. Know that because the earth rotates, the Sun, Moon, and stars all appear to move slowly across the sky.
- Observe and illustrate why the Moon looks a little different every day, but looks the same again about every four weeks.

Learning Looks Like This . . .

Pumpkin Decay: A Study of Change

Learners are always struck by how the simplest of things, when they pause to actually observe, think about, and discuss them, can convey some of the most important meanings in the world. Take a decaying pumpkin, a stock item in every elementary school classroom, around the first week of November. What if it remained on that science display table until May? What would change about it? Its color? its shape? its smell? its texture? What could a group of kindergarten students learn about the process of change by observing their tired old pumpkin specimen for several months as it languished in their classroom?

Children have lots of hunches about what would change, but are less clear about what impedes or speeds up the process of decay. One experimentally oriented class put its pumpkin outdoors on the classroom porch until spring, and lo and behold, it freeze dried! The most surprising result for most is that the smell, which mid-way in the six month long experiment is a cause for much annoyance, ends up closely resembling the earth! What better (and simpler) way to study an important process.

Grades 5-8 Learning Standards and Examples of Student Learning

Interactions and Cycles in the Earth System

- Demonstrate an understanding of the internal and external structure of the planet earth. Students might create models or diagrams that represent this structure.
- Explore and illustrate an understanding that heat flow and movement of material within the earth

moves the continents, causes earthquakes and volcanic eruptions and creates mountains and ocean bases.

- Evaluate conditions under which sedimentary, igneous, and metamorphic rocks form.
- Identify ways in which soil is formed by the weathering of rock and the decomposition of dead plants and animal debris. Give examples of how soil is essential for the survival of most life on land, and is the connection between many of the living and non-living constituents of the Earth System.
- Give evidence that water in the Earth System exists naturally in all three states and water continuously circulates through the earth's crust, oceans and air. e.g. water cycle. Provide examples illustrating that water plays important roles in regulating Earth's climate and shaping Earth's crust.
- Demonstrate an understanding that, like all planets and stars, the Earth is approximately spherical in shape. Use models to demonstrate how the rotation of the earth on its axis every 24 hours produces the night-and-day cycle.
- Present evidence that Earth's oceans are a reservoir of nutrients, minerals, dissolved gases, and life forms which are the major source of water vapor for the atmosphere and store of heat transported by ocean currents greatly affect Earth's climate.
- Observe and describe evidence that local climate changes over periods of years or decades, while global climate changes much more slowly. Give examples illustrating that climate changes over Earth's history have profoundly affected the evolution of life forms, and their present distribution.
- Examine and demonstrate evidence that weather can be studied in terms of properties of the atmosphere such as pressure, temperature, humidity, wind speed and direction, precipitation, and amount and type of clouds. Classify clouds by their, composition, height, and type of precipitation.
- Explain that clouds reflect much of the sunlight intercepted by Earth, while at the same time returning to Earth's surface a large fraction of the far infrared energy emitted from the surface. Describe ways in which these two effects are important elements in determining Earth's global climate.
- Examine and demonstrate evidence that the atmosphere and the oceans have a limited capacity to recycle materials naturally.
- Explore and describe that rain or snow falls and moves by gravity from higher to lower areas both on the surface and on the ground and that the natural flow region is called the watershed. Use maps to look at topography of nearby towns and make a model of the hills and valleys that make up the local watershed.
- Investigate and illustrate ways in which human activities, such as reducing the amount of forest cover, increasing the amount and variety of chemicals released into the atmosphere, and intensive farming, have changed the Earth's land, oceans, and atmosphere.

Earth's History

- Examine evidence and illustrate that the movement of the continents have had significant effects on the distribution of living things.
- Examine and describe ways in which rocks, fossils, ice cores and tree rings record events of Earth's history, documenting plate movements, volcanic eruptions, cycles of erosion and deposition, and the evolution of life. Examine ways in which the types, numbers and distributions

of fossils provides information about how life and environmental conditions have changed over time.

Earth and Space

- Observe and demonstrate that the patterns of stars in the sky stay the same, although they appear to move across the sky nightly, and different stars can be seen in different seasons.
- Explore and explain that telescopes magnify the appearance of some distant objects in the sky, including the Moon and the planets. Compare the number of stars that can be seen through telescopes to the number that can be seen by the unaided eye.
- Observe and illustrate that planets change their positions against the background of stars.
- Recognize and describe that the Solar System contains the central Sun, the known planets, their moons, and many asteroids, meteors, and comets that orbit the Sun. Describe ways in which the planets differ in size, temperature, composition, surface features, and number of rings and moons. Use this information to determine those conditions that make the Earth the only planet suitable for life.
- Demonstate evidence that the Sun is a medium-sized star located near the edge of a disk-shaped galaxy of stars, part of which can be seen as a glowing band of light that spans the sky on a very clear night.
- Illustrate that the Universe contains many billions of galaxies, and each galaxy contains many billions of stars.
- Observe and explain that Earth has a natural satellite, the Moon, that circles the planet approximately every 29 days. Use models to describe how the motion of the Moon about Earth and the location of the Sun relative to Earth and its Moon are responsible for the regularly occurring patterns of Moon phases, eclipses and tides.
- Give evidence that gravity is a force that produces an attraction between matter. Gravity pulls on or anywhere near the Earth toward the Earth's center and acts across space to hold the Moon in its orbit around Earth and the planets in their orbits around the Sun.
- Illustrate that the Sun produces energy and is the major source of heat and light for Earth. Examine evidence that energy received from the Sun as heat and light drives many processes on Earth's surface and in its atmosphere.

Learning Looks Like This . . .

A Rendezvous with Halley's Comet

The Christa Corrigan McAuliffe Center at Framingham State College is the site of the Challenger Learning Center, one of twenty-five teaching space centers set up as a memorial to the astronauts who died in the Challenger disaster in 1986. This wonderful earth and space science resource welcomes school groups from Grades 5 through 8.

When the bus carrying Mrs. M.'s sixth graders arrived at the Center, both students and teachers had high expectations. The curriculum theme for the 1994-1995 school year was "Rendezvous with Comet Halley" and the visitors had come prepared for their mission. The teachers had already attended workshops where they explored the curriculum materials, and the students had engaged in classroom activities where they learned about space travel, solar orbits, and the composition and temperature of comets.

One of the strengths of this curriculum is its use of instructional strategies that integrate technology with science content. Another strength is a strong emphasis on problem-solving. Both appealed strongly to these practical-minded sixth graders.

The goal of the mission, future dated 2061, was to navigate a space station to rendezvous with Halley's Comet and to launch a probe into the comet's tail. To accomplish the mission, students were organized as a crew divided into teams, each with its own task: Data (DATA), Medical Control (MED); Life Support (LS), Probe (PROBE), Isolation (ISO), Remote (REM), Communication (COM), and Navigation (NAV).

Students split their time between the Mission Control and the Space Station, and each student was responsible both to his team and to the mission. The mission required a formal communications protocol between ground control and the ship, which the students soon mastered and monitored on their own. From time to time, problems would arise which the teams were expected to solve with or without the help of the Center facilitators. When the ISO team sent data that was interpreted by Mission Control to be hazardous to the astronauts Mission Control worked the problem and presented a solution. Throughout the day, students stayed engaged and enthusiastic. It was cooperative learning at its best!

At the end of the day, many of the students were reluctant to leave outer space for the bus. Perhaps a few of them left with new expectations and aspirations.

Grades 9-10 Learning Standards and Examples of Student Learning

Matter and Energy in the Earth System

- Demonstrate an understanding that two fundamental forces acting in the Earth System are gravity and electromagnetism. Examine evidence that gravitational force acts between masses and is responsible for changes in the motion of objects on Earth and throughout the universe. Know that electromagnetic force holds matter together; recognize that the Earth itself acts like a magnet.

The Evolution of the Universe

- Give evidence that the universe is estimated to be over ten billion years old, and know some of the evidence for this estimate.
- Examine and describe evidence that led to the theory that the Solar System was formed from a cloud of gas and dust that condensed under the influences of gravity and rotation. Most of the mass of the cloud condensed to form the Sun at the cloud's center. The differences among the planets, moons, and other objects in terms of chemical composition and physical state were determined by the distances from the center of the cloud at which they condensed.
- Observe and illustrate that life is adapted to conditions on the Earth, including the force of gravity that enables the planet to retain an adequate atmosphere, and an intensity of radiation from the Sun that allows water to cycle between liquid and vapor.
- Examine and give evidence that life has changed the planet in dramatic ways. Photosynthesis has vastly increased the proportion of free oxygen in the atmosphere, and biological changes in the chemical composition of air and water hasten and shape the weathering of rock. Vegetation significantly affects the processes that change the landscape, and other life forms also make important contributions to changes in the face of the earth.

- Examine and describe evidence that the Milky Way is but one galaxy in a vast, ancient, and expanding universe, which contains a tremendous number of galactic clusters. Convey understanding that most of the Universe appears to be empty space, but that more and more kinds of materials are being discovered in interstellar space.

Geochemical Processes and Cycles in the Earth System

- Examine and describe evidence that rocks are continuously being modified by processes such as weathering, erosion, deposition, compaction, cementation, melting, heating (without melting), pressure, and crystallization. Describe ways in which sequences of these processes, collectively referred to as the rock cycle, occur continuously as materials move on or through Earth's upper crust.
- Examine models and illustrate that global wind patterns within the atmosphere are determined by the unequal heating between the equator and poles, Earth's rotation, and the distribution of land and ocean. Consequently, weather in northern and southern mid-latitudes tends to move eastward while in the tropics it moves westward. Illustrate understanding that atmospheric winds transport heat pole-ward from the warm tropics, helping to maintain Earth's climate.
- Relate and demonstrate an understanding that the solid crust of the Earth -- including both the continents and the ocean basins -- consists of separate plates that ride on a denser, hot, gradually deformable layer of the Earth. The crust sections move very slowly, pressing against one another in some places, pulling apart in other places. Ocean-floor plates may slide under continental plates. The surface layers of these plates may fold, forming mountain ranges. Describe the ways that the interconnection of Earth's layers by transfer of heat and material results in the movement of the crustal plates.
- Investigate and illustrate the theory that land forms of various shapes and sizes result from both constructive and destructive processes. Volcanic eruptions, sediment deposition, tectonic uplift, and other processes serve to build up land forms, and weathering and erosion wear them down. Topographic maps help to portray a variety of land forms and document change over time. Investigate ways in which rocks undergo changes from both physical weathering (e.g., abrasion, frost wedging) and chemical weathering (e.g., oxidation, solution, hydrolysis) to produce sediment and soils. Examine reasons why climate controls of these processes dominates.
- Examine and describe evidence that the "solid" Earth has a layered structure, with each layer having characteristic composition and physical properties. A solid inner core is surrounded by a liquid outer core, which in turn is surrounded by a large zone of dense mantle material. The crust is relatively thin compared to the other layers of Earth's interior. Examine ways in which the layers are interconnected by the transfer of heat and material by conduction and convection.

Matter and Energy in the Earth System

- Present evidence that energy is transferred through the Earth System by three mechanisms: radiation, conduction, and convection. Examine evidence that Earth receives energy from the Sun in the form of ultraviolet, visible light, near and far infrared radiation, and radio waves. This radiation has several fates: especially reflection and absorption; after absorption there is re-radiation but a tiny percent is captured by the biosphere.
- Examine and illustrate ways that conduction is responsible for the transfer of earthquake waves through Earth's interior, and of energy and materials between Earth's surface and atmosphere. Examine ways that convection moves energy through the Earth System in the form of winds,

ocean currents, and movements inside Earth's mantle and crust.

The Evolution of the Earth System

- Investigate and describe ways in which increasingly sophisticated technology is used to learn about the universe. Such technology includes visual, radio and x-ray telescopes, computers, space probes, and accelerators which give subatomic particles energies that simulate conditions in the stars and in the early history of the universe before stars formed.
- Examine and show evidence that stars vary in size, composition, mass, surface temperature and luminosity. Observe that the light received from a star contains information from which these quantities can be estimated. Know that this has made it possible to determine the source of energy within stars and to construct models for how stars evolve. Examine the ways in which current understanding of the evolution of stars suggests that for most of their lifetimes, most stars gradually change in size, surface temperature, and luminosity as they consume their nuclear fuel.

Earth in the Universe

- Examine and construct models to observe ways in which Earth's global climate is determined by the planet's distance from the Sun, the tilt of its spin axis with respect to the plane of Earth's orbit, the length of the planet's day compared to the length of its year, the composition of its atmosphere and oceans, and the properties of its surface. Describe how the seasons are due to the tilt of Earth's spin axis with respect to the plane of its orbit around the Sun. This causes unequal heating of Earth's surface by the Sun's energy, varying with latitude and with time of year.

Geochemical Processes and Cycles in the Earth System

- Describe how the global climate varies on several time scales in part due to the changing energy received from the Sun. The energy output of the Sun has varied slightly over periods of hundreds to thousands of years. Additionally, on time scales of tens of thousands to hundreds of thousands of years, the intensity and distribution of the energy received by the planet has varied as a consequence of Earth's continually changing orbit.
- Relate understanding that over a period of a few days, water vapor rises from Earth's surface into the atmosphere. Winds carry the vapor poleward where it condenses to form clouds and precipitation, releasing the energy initially used to evaporate the water. Over several weeks water flows down a river to the sea. Over many years water flows through underground aquifers.
- Investigate and illustrate ways in which carbon, sulfur, nitrogen, and other elements are continuously cycled through the Earth System. These cycles involve both the global distribution of these elements and their compounds among various reservoirs, and the rate at which these substances transfer between reservoirs through chemical reactions. Investigate ways that the biosphere is an important component of many of these cycles.

Learning Looks Like This . . .

Environmental Engineering and Technology

Students at Cambridge Rindge and Latin School can take a course in the junior or senior years that applies their earth and space, physical and life science knowledge to study their immediate environment. Students design, test and build boats, sails and oars with the help of a classroom-designed and constructed wave tank. Students use topographic, geologic, and soil maps as a basis for developing orientation and surveying skills, constructing three-dimensional models, delineating watersheds, performing hydrological studies, and exploring the history of surface geology in Cambridge and its immediate surroundings. Students classify and collect basic wetland soils, plant, and animal forms through explorations by foot on Cambridge's wetlands and by boat on its water bodies. This course is titled Environmental Engineering and Technology, and it is offered by the Rindge School of Technical Arts, for the Industrial Technology and Engineering Pathway.

Strand 3: Technology

Lifelong learners are able to understand and apply the design process and the use of technology in society.

"[M]any parts of our world are designed -- shaped and controlled, largely through the use of technology -- in light of what we take our interests to be. We have brought the earth to a point where our future well-being will depend heavily on how we develop and use and restrict technology."

Science for All Americans (1989) p. 97

Science and technology are closely linked; both are practices based on inquiry. For example, investigating the salinity of the water in Vineyard Sound is a pursuit of science, while creating a way to make this salt water drinkable is a pursuit of technology. Simply stated, science tries to understand the natural world, while technology tries to solve practical problems.

Technology's impact on society is more direct than that of science, and as it provides tools for understanding of natural phenomena, it often sparks scientific advances. The development of the telescope in the seventeenth century, for example, led to rapid advances in the field of astronomy.

Technology expands our capacities to understand the world and to control the natural and human made environment. Technology asks questions like *"How does this work?" "How can this be done?"* and *"How can this be done better?"* Owning the questions of technology requires that students engage in problem solving by designing, building, and testing solutions to real-world problems. The ways in which problem solving in technology parallels investigation in science is shown in Figure 1 on the following page.

The Learning Standards for Technology are divided into two domains: *(a) The Design Process and (b) Understanding and Using Technology in Society*. The latter domain includes the following topics: 1. The nature and impact of technology; 2. Technology yesterday, today and tomorrow; 3. The tools and machines of technology; 4. The resources of technology; and 5. The technological areas of communication, construction, manufacturing, transportation, power technology, and bio-related technology. The Glossary at the end of this strand defines these technological areas.

During the elementary school years, students' experiences with technology are hands-on and exploratory; they encounter technology issues long before they know what technology is. In middle school, they move on to more intricate design process and problem-solving tasks. The design process involves the consideration of multiple solutions and design evaluation. Students also begin to develop strategies for tackling problems and begin investigating technological products and systems. At the high school level, students sharpen their analytical skills by considering design problems that have not necessarily been solved before. Using the design process, they work with elaborated design constraints, implement a solution that conforms to the constraint, and use planned criteria for evaluation, while also learning to examine and evaluate other peoples' work.

Students are experienced technology users before they ever 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. They are also natural explorers and inventors, inveterate builders of sand castles at the beach and forts under the furniture.

But while most **students in grades PreK through four** are fascinated with technology, they need to experience the mechanisms, principles, and design constraints that underlie technological solutions. As they learn more about these, they begin to understand the relationship and differences between human-made and natural objects. Presented with technological problems that are clearly stated and related to their daily lives, elementary school children can explore them and carry out design solutions. They may also come to realize that a solution to one problem may lead to another problem.

Students in grades five through eight need to pursue technological questions that emphasize creative and critical thinking, problem solving, decision making, and research. As they work through problems, students should begin to identify technological resources and know their appropriate uses. Early in this grade span, students acquire basic skills in the safe use of tools and machines. Somewhat later, they begin to appreciate the impact of technological changes throughout history and can relate specific technologies to time and place. Real-world problem-solving exercises now take place in interdisciplinary settings as well as in the technology classroom.

In the grades nine and ten, students work with more advanced problems and designs while turning their attention to some of the complex issues that dwell in the interface between technology and society. Such topics might include the historical development of technology, global competition for technology, the social control of emerging technologies, technological resource management, communications monopolies, manufacturing processes, transportation technology, and power production.

By the time students reach high school, they can understand the connections between science and technology. But they will do so only if not discouraged from taking courses in both fields. In most high schools, course offerings divide at the high school level, and students have to choose among the college prep, vocational, and technical alternatives. All too often, students in the vocational pathway take a minimum number of science courses. Recent federal legislation (The School to Work Opportunities Act, and the Carl Perkins Act of 1990) has provided strong support for "tech prep" and workplace learning. Both acts encourage movement away from a "skill and practice" approach to vocational education toward an approach that stresses the connections among the academic and technical disciplines. Related to this, technology education places a stronger emphasis on designing, building, evaluating and using real artifacts.

Technology learning standards for grades eleven and twelve fall under the same headings as for grades nine through ten. Technology study in these last two years builds upon, extends, and applies knowledge developed in earlier years. At this level, students develop understanding and expertise by relating classroom learning in technology to community and/or worksite experience or by studying key technology topics in depth. Independent studies can help students develop leadership skills.

Students in the upper grades should have the opportunity to choose from a variety of technology programs, and each course of study should be designed around a strong intellectual core. Students may then choose courses best suited to their own interests and career goals. Options for study might include:

Advanced Placement Physics, Chemistry, Biology, Earth/Space Sciences Applying Principles of

Technology/Physics Seminar, / Biology Seminar; Earth Science seminar: Biomedical Engineering; Biotechnology; Environmental Engineering and Technology; Global Manufacturing Systems; Science/ Technology/ Society; Technical Internships in: Graphic Animation; Health Sciences; Technical Internship in Graphic Animation; Technical Internship in Light/Wave Communication; Technical Internship in Video Production.

The learning standards for Technology are organized under two domains for each grade span: The Design Process, and Understanding and Using Technology in Society. The latter, Using Technology in Society is organized into five categories: The nature and impact of technology, Technology yesterday, today and tomorrow, The tools and machines of technology, The resources of technology, and The technological areas of communication, construction, manufacturing, transportation power and bio-related technologies.

These learning standards often use the processes of inquiry to illustrate the way technology content understandings might be explored. The process chosen as an illustration does not imply that this is the only or best way that content understandings may be addressed.

Grades PreK- 4 Learning Standards and Examples of Student Learning

The Design Process

- Identify a simple current technological problem.
- Implement a solution by constructing a device using materials provided.
- Evaluate the solution in terms of whether it meets the goals. See whether your solution worked, e.g., whether the tower was strong enough to hold a one-pound weight.
- Communicate a problem, design or solution using drawings and words.
- Propose ways to improve the solution.

Learning Looks Like This . . .

Tower Design

Mr. Keytone teaches kindergarten and first grade students and wants to develop curriculum projects that will be accessible to his youngest kindergartners as well as his most mature first graders. The block area has always been popular in his classroom, so Mr. Keytone decides to expand upon his students' interest and passion for block building by introducing challenges for building other kinds of structures. He also hopes that elaborating on the materials used and the scale of construction might entice more girls to stay involved. The challenge he sets for his students is to build towers with various materials (blocks, Legos, paper cups, newspapers, straws); to reach specified heights, and with various bases. Later, students continue their explorations of structures by building taller more elaborate towers from rolled newspapers and tape, and see how high a tower they can build. At the end of the project, they share their solutions with their classmates, comparing their results orally and using chart paper.

In these activities with commonplace objects, students are looking at the structure of things by experimenting with three concepts: the center of gravity; the relationships determining the distribution of forces in their structures; and exploring space in a vertical direction. This project involves the key aspects of the design process, stating a problem, considering solutions and choosing one, designing or making a device, carrying out a plan (or testing a device) and improving or seeking a new solution. At the primary grade level, these occur informally.

Grades PreK-4 Learning Standards and Examples of Student Learning

Understanding and Using Technology in Society

The nature and impact of Technology

- Describe differences between natural objects and objects made by people.
- Identify daily activities that involve the use of technology, e.g., communication, transportation. Identify different tools that you might use to accomplish a particular task.
- Describe how technologies may have positive and negative impacts on people and the environment.
- Describe ways in which technological tools and methods allow us to better learn about the laws of nature.

Technology yesterday, today and tomorrow

- Document how technological inventions and innovations have been developed by women and men from various racial and cultural backgrounds including individuals from Massachusetts. Describe an invention originating in the Commonwealth of Massachusetts.
- Examine evidence that where people live, and how they communicate and travel reflect technological changes.

The tools and machines of Technology

- Describe ways in which tools and machines are used to process materials, energy, and information.
- Demonstrate use and care of simple tools.
- Document that people are always inventing new ways to get things done. Describe an instance in which someone learned to do something a new way when the old way worked.

Resources of Technology

- Use a variety of materials such as wood metal, plastic, fabric and clay to make simple products.
- Identify materials that can be recycled and those that cannot. Give evidence that local recycling rules and laws reflect this.

Technological areas of communication, construction, manufacturing, transportation

- Explain that messages are communicated using tools such as pencils and computers.
- Observe and model many types of structures (i.e., residences, skyscrapers, bridges, tunnels, airports). Identify similarities and differences among structures.
- Describe and experience how objects can be made from materials such as wood, plastic, paper, metal and clay by processes often involving machines.
- Describe how people and goods are transported using boats, automobiles, trucks, airplanes and space vehicles. Illustrate the ways in which you most often travel.

Learning Looks Like This . . .

Construction Inside and Out

Ms. Green held up a wooden block from the construction area. "How many of these blocks can a piece of paper support," she asks?

"None," her second graders answer, "because the paper isn't strong enough."

One student tries to stand a sheet of paper on its end, demonstrating how easily it bends. Ms. Green tells them that the paper can support this block and a lot more! "How can a thin piece of paper hold so much weight?" they ask.

Ms. Green challenges the students to bend and fold the paper in a way that it will support a wooden block. One student folds her paper in the shape of a column. Ms. Green calls other students' attention to it. Another student asks where can they find columns in their school.

Ms. Green asks the students if they know what is holding up the roof of their classroom? One student answers that a long beam is in the ceiling and that this beam supports the roof. Ms. Green then asks the students what supports the long beam so that it won't fall on them? Students give different answers to the question but most aren't sure. She takes her students to the construction site down the block on the following morning where they see a new school under construction with long beams and steel columns.

When they return to the classroom they experiment with making columns of different shapes and heights out of paper. They have to test the strength of their columns by seeing how many wooden blocks they can place on top of the column, one at a time, until the column collapses. Students are surprised by the number of blocks their columns can support. This helps them think about how great is the amount of weight the columns in their classroom support.

Grades 5-8 Learning Standards and Examples of Student Learning

The Design Process

- Identify and work on their own problem or one developed by a peer. Investigate which tops might spin the longest based on design features.
- Explore and illustrate possible solutions and from these propose one solution.
- Make a plan for building a device considering the limitations of the material, and including multiple views.
- Evaluate designs, devices or solutions and develop measures of quality. Decide whether design limitations have been followed.
- Communicate the process of technological design.

Learning Looks Like This . . .

Designing Solar Homes

Mr. Appleton and Ms. Rose teach seventh grade in a middle school; Mr. Appleton teaches science and Ms. Rose teaches technology. Their students are studying alternative sources of energy in their general science course. Both Mr. Appleton and Ms. Rose are coordinating their classwork to help students develop projects for their school-wide energy fair. Mr. Appleton has been concerned that the physical science understandings concerning light, energy, materials and temperature described in the students' textbooks are not really accessible in the ways they are presented. He talks with Ms. Rose about his belief that these physical science principles and concepts need to be made more accessible to students for their projects to result in significant learning. He expresses the desire to have this year's projects connect to students' ongoing science and technology work, building on their questions and problems as well as reflecting the group collaboration that typifies their classwork. The Solar House Design Project below is what he proposes as a step toward building conceptual understandings through independent projects.

In this project, the fundamental understandings of physical science and the skills of technological design are closely intertwined.

Solar House Design Project

Your challenge is to design a model house that can be heated efficiently by the sun. You'll be building a model of a solar house for this project using a 150-watt lamp as a model sun.

Design Constraints

The following materials may be used in constructing your model solar house:

- Up to 3000 square centimeters of corrugated cardboard The corrugated cardboard must be approximately 4mm thick.
- Plastic wrap (normally used in the kitchen) or acetate (normally used for transparencies for the overhead projector). This material may be used only for windows.
- Cellophane tape or glue, only for joining other materials.
- One container to be placed inside the model. Maximum volume: 1/4 liter. It can be filled with anything you want (water, sand, etc.)
- One 150-watt flood light. You may use a piece of cardboard to shield the light from your eyes. You may not add external reflectors.
- Paint: You may paint the model and any of its components any color you want.

Note: The face of the light bulb must be 25cm away from the model.

Criteria for Evaluation

As you compare your solar house models, more efficient models will be those which:

- Achieve a greater temperature difference between the inside of the model and the room temperature in your classroom.
- Have a slower cooling rate.
- Have a larger internal volume.

Thinking about your solar house design

In designing your model you will need to take into account competing factors. For example, a larger internal volume might reduce the maximum possible temperature in your model. Larger windows might allow more heat in, but they also might permit more heat to escape. Think about it. Perhaps you will decide to set priorities, that is, to consider some parameters more important than others. In any case, do not disregard any of the three criteria for evaluation (listed above). Rather, think how you will take them into account.

It is important to keep each of the parameters within a reasonable range. An internal volume that is too high might make it impossible to achieve measurable differences in temperature. Design is a process of exploration. Try using the given materials in imaginative ways. For example, can any of the allowed materials be used as insulation?

Grades 5-8 Learning Standards and Examples of Student Learning

Understanding and Using Technology in Society

The nature and impact of Technology

- Explain how technological progress has been the result of cumulative work over many centuries by men and women from various cultures and races. Choose an example of such an invention that formed the bases for a major change in the way we live our lives.
- Describe ways that technological devices have improved the quality of life for individuals. Choose an example of such an invention that formed the bases for a major change in the way we live our lives.
- Describe ways that technological advances may be accompanied by negative side effects.

Technology yesterday, today and tomorrow

- Explain how the evolution of technology led the change from an agricultural to an industrial to an information based society.
- Provide evidence that technology is growing at a faster rate today than ever before in history.
- Describe ways in which innovations and inventions address human biological, physical and psychological needs. Choose an invention that has contributed to your happiness and find out about how it came to be.

The tools and machines of Technology

- Document ways that a range of tools and machines, such as measuring, hand and optical tools, are used to implement solutions to design problems.
- Use tools, materials, and machines safely and effectively.

Resources of Technology

- Explain how the choice of materials depends upon their properties and characteristics and how they interact with other materials.
- Use the results of material tests (i.e., hardness, tensile strength, conductivity), to suggest appropriate uses for materials. Explain what certain metals are useful for, and give examples.
- Model the ways that multiple resources are used to develop new technologies. These include: people, information, tools and machines, materials, energy, capital, and time.

Technological areas of communication, construction, manufacturing, transportation, and power technologies

- Give examples that information can be communicated both graphically and electronically by a range of technological processes.

- Explain how a manufacturing enterprise produces a product by converting raw materials into goods. Choose a recreational product, such as sports shoes or a football, and research its manufacturing history.
- Identify the processes used in construction: site preparation, building, and finishing a structure.
- Compare how transportation systems are devised to transport people and products on land, water, air, and in space.
- Describe how power systems are used to convert and transmit mechanical, electrical, fluid, and heat energy. Describe limited (i.e., fossil fuels), unlimited (i.e., solar, gravitational) and renewable (i.e., biomass) energy sources.

Learning Looks Like This . . .

Community Newsletter

Ms. Wong's class has been asked to help collate the community's monthly newsletter. They find the task to be quite time consuming and are looking for ways to streamline their process. Alyce remembers seeing a CD ROM disk in the library that described an early twentieth-century assembly line for making automobiles, and proposes that they consider creating an assembly line to help their process. She explains to her classmates that an assembly line is used in manufacturing to build a product and is designed to divide up the labor so that each person has only one job to perform.

The students agree to try an assembly line approach and select a design team to develop their strategy. The team determines what jobs need to done and assigns one or more members of the class to each task.

To solve any problems that might have been overlooked and to help each member of the class become familiar with his or her task, they do a trial run. The approach works well, and the students are amazed by their new efficiency.

Grades 9-10 Learning Standards and Examples of Student Learning

The Design Process

- Identify a problem or design opportunity that has not necessarily been solved before.
- Propose designs and choose among suggested solutions. Sketch a solution to scale in 3 views and contribute more sophisticated designs and prototypes.
- Implement a proposed solution that conforms to the design constraints.
- Evaluate the solution and its consequences against planned criteria.
- Communicate the problem, process and solution.
- Redesign the solution.

Learning Looks Like This . . .

Making a Light Bulb

One young woman takes the insulation from a piece of copper wire. Her partner wraps a single strand of nichrome wire around a pencil to form a coil that will be used for the filament of the light bulb they are building. As they work, they sketch and write notes in their journal about the strategies they use. These initial building experiences, and coaching from their teachers lead them to ask questions about the materials and the design of light bulbs. They wonder:

- Why the filament burns faster in their bulb than in a commercial light bulb?
- What would happen if they changed the length of their filament?
- Would it make a difference if they didn't coil their filament?
- How many different types of light bulbs are there in homes?
- How can they make a longer burning light bulb?

Their questions set the stage for further work and independent projects. The message from their teachers is clear -- It is okay to learn from mistakes. They become comfortable taking risks. While classroom experiences are coupled with discussion, short lecture, guest speakers, research, and field trips, independent projects constitute the major proportion of students' work.

These students are taking a course with Ms. Mahoney, a tenth grade science teacher, and Mr. Soo, a technology education teacher, who have teamed up to teach a course in materials science and engineering technology (MST). Their course integrates chemistry, engineering, physics, mathematics, writing, and technology education and is based on the conviction that students learn best by asking questions such as *"What happens if?"* rather than *"What is the right answer?"* In their classes, students sketch plans, record and verify observations, and note progress as part of project work. They ponder, plan, experiment, make mistakes, refine designs, and create products. This mirrors the work of real scientists and technologists as they work in their laboratories.

Study of the nature and behavior of materials, e.g., metals, ceramics, polymers, and composites are the subjects of the curriculum program they use. The Making a Light Bulb project is part of their program of metal study. In this project, the core understandings of physical science, e.g., energy, heat transfer, and resistance and the skills of technological design are closely intertwined. By experimenting and actually working with their hands to discover the properties and nature of materials, students experience the ways in which doing science and technology actually occur in the workplace. These two teachers hope that this approach will provide an entry point for many students who are not reached by traditional science or technology courses.

Grades 9-10 Learning Standards and Examples of Student Learning

Understanding and Using Technology in Society

The nature and impact of Technology

- Give examples of how a technology device, service, or system is used for a particular purpose. Choose a device, service or system and explore it in depth.
- Describe ways in which technological impacts can be multidimensional (i.e., economic, social,

environmental, political).

- Give examples of how technology has played a key role in the operation of successful Massachusetts and United States businesses.
- Describe ways in which technological inventions and innovations stimulate economic competitiveness and are translated into products and services with marketplace demands.
- Participate in technological society as active citizens, consumers, workers, employers, and family members.

Technology yesterday, today and tomorrow

- Describe examples of new and emerging technologies in areas of communication, construction, manufacturing, transportation, power, and bio-related technology.
- Provide examples of how technology creates new jobs and makes other jobs obsolete. Develop an example of how this shift in work needs is occurring today.

The tools and machines of Technology

- Describe examples of the wide range of contemporary tools that are used to process and measure materials, energy, physical phenomena, and electronic signals. Some of these include: measuring instruments, computer-based tools, and data-capturing sensors. Choose a type of tool and investigate its use.
- Use complex tools, machines, and equipment to solve problems.
- Identify appropriate ways to select, operate, maintain, and dispose of technological devices.

Resources of Technology

- Identify particular characteristics of material resources, i.e., synthetic, composite, and biological. Explain how various energy sources and forms of information are also resources with specific characteristics.
- Discuss issues of resource management including safety, costs, environmental and political concerns. Discuss a current example such as waste management and nuclear power systems.

Technological areas of communication, construction, manufacturing, transportation, power, and bio-related technologies

- Give examples of how combinations of graphic and electronic communication processes are used in developing high technology communication systems.
- Describe uses of material conversion processes, i.e., separating, forming, conditioning and combining, in production processes.
- Identify ways that manufacturing processes have changed with improved tools andtechniques.
- Compare how existing transportation technologies convey people and products globally.
- Give examples of ways in which technological processes could adversely affect the environment. Choose a current example from your local news to investigate.

Learning Looks Like This . . .

New Directions

As participants in a National Science Foundation project, three building trades classes at a vocational technical school constructed two new additions to their community playground. The first was a Light Track, an eighty foot long, five foot high, wooden structure on posts with forty-eight lights and bells installed along the side. The second was a Timer, a giant digital stopwatch housed in a separate wooden kiosk. Students considered complex structural and transportation issues with the help of their instructors. They faced questions about placement, safety, and durability for pipes, fittings, and electrical connections that had never been designed before. Since the site was on a hill and the structure had to be perfectly level, the students learned to use surveying tools, mechanical digging tools, and computers for calculations of measurement. At the end of their three months of work, the students spoke with pride about community children playing on these structures that they had recently wondered if they could ever build.

Grades 11-12 Learning Standards and Examples of Student Learning

The Design Process

- Identify a problem that has not necessarily been solved before. Involve invested parties in the problem identification.
- Propose designs and choose between alternative solutions.
- Implement a proposed solution that conforms to the design constraints. Implement CAD drawings.
- Evaluate the solution and its consequences against planned criteria. Use quality control procedures similar to those in an industrial setting.
- Communicate the problem, process and solution.
- Redesign the solution. Initiate new approaches.

Grades 11-12 Learning Standards and Examples of Student Learning

Understanding and Using Technology in Society

The nature and impact of Technology

- Give examples of how technology influences business and government policies and actions.
- Predict ways that technology will change in the future and will have an impact on individuals, careers, family, and society.
- Identify problems caused by globalization such as standardization, copyright, patent infringements, value added cost, etc.
- Explain how technology plays a major role in making a country a world power. Document how this was important during World War II.

Technology yesterday, today and tomorrow

- Describe the process through which an invention is patented. Provide examples of products or processes patented by males and females of various cultures and races.
- Give examples of how some technologies will become obsolete in the next two to five years and emerging technologies in the areas of communication, construction, manufacturing, transportation, power, and bio-related technology will replace them. Consider what this might mean for your life when you are working.

The tools and machines of Technology

- Use a wide range of tools and instruments to analyze, adjust, and maintain mechanical, electronic, hydraulic, pneumatic, and electrical systems.
- Describe ways in which contemporary problems in the areas of communication, construction, manufacturing, transportation, power, and bio-related technology can be resolved through the research and use of technology.

Resources of Technology

- Identify benefits and costs associated with the use of resources in technological ventures. Choose one resource and examine its benefits and costs as it pertains to your life.
- Explain how technology assessment analyzes the properties of resources, their availability, the ease of processing and disposal, and economic considerations.

Technological areas of communication, construction, manufacturing, transportation. power, and bio-related technologies

- Describe how messages may be designed and communicated containing integrated written, audio, and video portions. Identify the purposes of communication: for information dissemination, persuasion, entertainment, and/or education. Create a multimedia presentation with a particular purpose in mind.
- Give examples that automated manufacturing processes that have transformed industries. Describe how automated continuous manufacturing enterprise involves design, organization, finance and a combination of material conversion processes to produce products.
- Model how contemporary and nontraditional construction practices (for example, fabric structures, geodesic domes, foam structures) are used to create a structure.
- Describe examples of how internodal transportation systems transport people and products efficiently with minimal risk to the cargo and to the environment.
- Explain how industrialization brings an increased demand for energy usage and also leads to more rapid depletion of the Earth's energy resources.
- Give evidence showing how efficient use of technology can slow the rapid depletion of the Earth's energy resources. Choose an example of this from your local newspaper and explore it.
- Describe how technology forecasting determines the effects of various bio-related developments, e.g. increased plant growth, or water purification systems.

Glossary: Definitions for Areas of Technology

The areas of technology covered in this framework are: Human Generated Technologies including: communication, construction, manufacturing, and transportation, and Processes of Technology including: power technology and bio-related technology.

- Communication technology uses technical means to connect a sender (source of information or ideas) with a receiver. The connection is called the communication channel. After processing there is feedback that provides a channel from the receiver back to the sender. The communication system uses information as its basic input and delivers it to people or machines. Some of the categories of communication are: graphic production systems that involve different types of printing, technical design systems that involve the use of CAD and drafting; optical systems that involve the use of photography and holography (laser); audio/visual systems that involve the use of radio and television; and data communication systems that involve the use of computers.

- Construction is used to produce structures on the site where they are erected. These structures can be categorized as residential, commercial, or industrial buildings, or they can be civil structures such as roads, dams, bridges, and pipelines. The basic input to construction is raw and manufactured materials and products. These are used in conjunction with other resources to create the desired building or other structure. The major construction processes include: preparing the site for the structure, setting foundations for the structure, erecting the structure, installing utilities when required, and completing the site.
- Manufacturing changes the form of materials to increase their worth. The processes in manufacturing convert raw materials into industrial goods, which can be used to develop consumer and industrial products. Manufacturing processes are grouped into four major areas that extend from finding the material resource through the production of the final product. These processes are locating material resources, extracting material resources, producing industrial materials (primary processing), and producing products (secondary processing).
- Transportation relocates people and cargo. The process generally involves a vehicle that moves along a pathway, which can be a constructed roadway or railway or designated routes in air, in water or in space. The exceptions to this definition are pipelines that are "vehicle-less" transportation systems. Therefore the categories of transportation are land, sea, air, and water.
- Power technology deals with the process of converting energy into a useful product. The four basic categories of power are electrical, mechanical, fluid, and heat.
- Bio-related technology applies to the production process techniques relating to the products of agriculture, and the biological processes tied to fuel and material production such as waste treatment, recycling, and hydroponics.

Strand 4: Science, Technology, and Human Affairs

Lifelong learners understand questions and problems of Science and Technology in the context of Human Affairs.

Advances in science and technology, such as the ability to circumnavigate the globe and to communicate electronically, have changed the way we view ourselves and our place in the universe. They have also informed our attempts to solve human problems at the local and global levels. So entwined are science and technology in the affairs of the world, that students must be encouraged to look up frequently from their studies to see where science and technology are leading them.

Owning the Responsibility for Science and Technology

Owning the questions in science and technology requires that practitioners accept responsibility for evaluating the impact of their activities in the real world. Questions like *"What does this mean for the next generation?"* and *"How can we lessen human impact on the environment?"* place science and technology in the context of human affairs. These are questions that responsible practitioners ponder every day. As educators we need to ask similar questions: *"How can our students come to own these questions, too?"* and *"How can we anchor their studies in the powerful and motivating context of human affairs?"*

When scientific and technological inquiries are embedded in the context of human affairs, students are more likely to view human and environmental issues as important to their course of study. In turn, they come to understand the relevance of science and technology in their lives.

When seventh graders gathered sound-level data in their school ("How Loud is Loud?"), they encountered issues of comfort and safety associated with high decibel levels. They not only discovered that their parents really believed their music was too loud, but also that noise pollution was a concern to their community and that there were laws to control it. In the Water Taste experiment, students confronted the belief, contradicted by their scientific investigation, that the water in the fountain used by the older kids "tastes better" than the water in the fountain used by the younger kids.

Taking Science and Technology into the Community

Investigating a question that originates in their own lives provides students with a model for learning that is not dependent on the classroom, a single teacher, or a particular course of study. In a similar way, practicing the ways that scientists and technologists address complex societal issues helps students appreciate the challenges we face "in the real world."

When high school students are called on to devise a way for getting drinkable water to all of Boston, they begin to understand the problems associated with limited resources and densely populated areas. When they bring cross-disciplinary skills to bear on the problem by studying ancient Roman aqueduct systems, they begin to appreciate the technological feat of the Quabbin Reservoir system. The reservoir project engages students in debate, mathematical designs, written arguments, and the study of historical developments associated with people's need for fresh water. It also involves them as citizens of the world.

Recognizing that our resources are limited and making responsible decisions about their use is not just a civics lesson. It is a Science and Technology lesson, and it can be taught at all grade levels. Elementary school children can grasp the repercussions of overfishing Georges Bank, one of New England's greatest food sources, just as they can come up with ideas for reducing the amount of trash their class generates over the course of a week ("Too Much Trash?"). Similarly, projects like the community-built science playground ("New Directions") give older students a direct way to contribute to the well-being of younger students.

The following vignette describes a large and wonderfully creative study that teaches students how people must work together to address issues related to community resources.

Learning Looks Like This . . .

The Ten Mile River Project

The Ten Mile River wends its way through four Massachusetts communities before meandering into Rhode Island toward its final destination, Narragansett Bay. The river's impact on the history of its watershed has been significant, from providing precious water for the survival of the earliest settlers through powering the factories that lined its shore during a rich industrial era. But the price the river has paid for its generous contribution has been great. Once ranked one of the most polluted rivers in Massachusetts, the layers of sediment in its bed attest to the careless dumping of heavy metals and other pollutants throughout the ages. But recent years have seen tremendous improvements in water quality. With the introduction of the Federal Clean Water Act and the help of industries throughout the watershed, the Ten Mile River is returning to a cleaner, more natural state.

The history and impact of the Ten Mile River on its surrounding communities have led to an exciting interdisciplinary study for students in its watershed. The study began with a workshop for teachers led by a PALMS Specialist from the Lloyd Center for Environmental Studies, in South Dartmouth, who helped teachers develop questions about the river and debate such issues as whether land along the river should be held by municipalities or maintained by such organizations as Ducks Unlimited or the Massachusetts Audubon Society.

The teachers became excited about the project and began sharing it with their classes. In turn, the students began doing science beyond the confines of their classroom. As the end of the school year approached, the teachers formed a support group to expand the river project. With the start of a new school year, students and teachers from North Attleboro's seventh and eighth grades joined and worked with the Science Specialist from the Lloyd Center and the newly opened Audubon Society in Attleboro.

Teachers began working more in the field with their students, and found that they needed additional support. The Ten Mile River Watershed Alliance, a local non-profit citizen group, helped solve this problem by training adult volunteers. These newly trained leaders assisted teachers by running specific activities along the river.

Accurate recording of student field data became possible through the use of spreadsheets on laptop computers purchased through local funding supplemented by a grant from the Richardson Fund, a local source. Small groups of students were trained in the use of the laptop (including spreadsheets, report writing, charts and pop-ups) by a science and math resource teacher. Students then trained other students, and additional support was given to classes by the computer specialist in each building. When the need to link data teams arose, training for teachers was provided by a computer scientist from Wheaton College.

As this program grew, students became more committed to improving the quality of the watershed, and they sought additional business and community support. The Ten Mile River Alliance subsequently provided a vehicle for classes to officially adopt sections of the river. As students became involved in testing water samples, they began to wonder whether more sophisticated equipment would produce similar results. When Texas Instruments was contacted, they agreed to provide engineers to perform water quality tests for student projects.

The yearlong river adventure culminated in an evening presentation of data to the community. Student presentations were heard by parents, local and state government officials, community members, and Partners from Texas Instruments, Wheaton College, Lloyd Center, and the Massachusetts Audubon Society.

Understanding the Risks of Science and Technology

Science and technology have not always meant progress. Indeed, they can lead to harm in the environment and jeopardy to human well-being. For these reasons, responsibility and stewardship are key elements of science and technology teaching.

Marine biologist Rachel Carson first enumerated the dangers of developing New England's coastal marshes, arguing that it would disrupt the breeding grounds of many salt water organisms. Carson also fought hard against the indiscriminate use of pesticides, bringing to national attention their deleterious effects on the ecological balance and human health (Silent Spring, 1962). *The fifth-grade students who* *investigate "The Return of the Osprey" are likewise concerned with issues of ecology, responsibility, and stewardship.*

Today's students need to understand that many scientific and technological discoveries entail complex and unexpected human affairs issues, and they must be unafraid to address them. As part of education, teachers can encourage students always to imagine the effects of an indiscriminate or unprincipled use of science and technology. For example, eleventh and twelfth grade students might interview citizen activists about community concerns surrounding the Seabrook and Plymouth nuclear power plants. Similarly, students interested in careers in the medical sciences might mount a debate on the ethical concerns of organ transplantation.

Taking Inspiration from Science and Technology

The following Learning Standards inspire students to own the questions of science and technology and to accept the responsibility that comes with pursuing them. The framework ends with a powerfully motivating vignette, "A Passion for Students, Teaching, and the Sea," that explores some of the ways that teachers and students in the Commonwealth can investigate interesting problems of science and technology while keeping their hearts and minds firmly committed to the world of human affairs.

Grades PreK-4 Learning Standards and Examples of Student Learning

- Give examples to show that many of today's technologies were not part of the world of their parents or grandparents.
- Describe some ways in which science and technology have changed the way people do their work and live their lives.
- Give examples to show that the decisions we make as individuals have effects on others people.
- Explore and describe how science and technology have also created problems we need to solve.
- Give examples that we (as individuals, groups and communities) can make decisions that change the natural environment.

Grades 5-8 Learning Standards and Examples of Student Learning

- Describe situations in which science, technology, and society have influenced each other in the past.
- Identify the influences science and technology have on today's society.
- Give examples that the decisions we make as individuals, groups and communities can affect society and the natural environment, and that these changes are not always easy to reverse.
- Recognize and demonstrate that while technology can help us to manage societal and environmental problems, it can also have a negative impact on society and on the natural world.

Grades 9-10 Learning Standards and Examples of Student Learning

- Identify situations in which science, technology, and society have influenced each other in the past and describe how science and technology have been an integral part of the history of human society.
- Describe situations that illustrate how scientific and technological revolutions have changed society.
- Develop skills in applying scientific knowledge to make decisions about problems at the community, state, national and international levels, and recognize that using these skills responsibly is an essential part of being a citizen in today's world.
- Describe ways in which technological development has been influenced by the culture of the society and by the resources available to that society.
- Give evidence that rapidly changing technology affects global competition and jobs.

Grades 11-12 Learning Standards and Examples of Student Learning

- Give examples of the influence science and technology have on today's society.
- Recognize that the key problems that scientists address can change in response to changing societal pressures.
- Argue and defend the position that while technology can be used to solve societal problems, technology can also have a negative impact on people and the environment.
- Develop skills in applying scientific and technological knowledge to making decisions about problems at the community, state, national and international levels, and recognize that using these skills responsibly is an essential part of being a citizen in today's world.

Learning Looks Like This . . .

A Passion for Students, Teaching and the Sea

"There are more people alive today than have ever died." I wrote that sentence on the board the day after I heard them spoken by Robert Ballard, the Woods Hole Scientist who found the Titanic, the Lusitania, and the Bismark. When the students read it they immediately began active dialogue with each other until one asked "What are we supposed to be doing today?" I told them that they were doing it, reacting to the statement just as I had and thinking about the implications for us.

I teach ocean science to middle school students in Cape Cod. I was frustrated with the general science course I was teaching, and believed I could make it better and more relevant using local applications. I scrapped a botany program that was based on corn, and a zoology program based on perch dissection, and convinced the principal to let me try out an ocean-centered approach.

My major focus was getting the students involved in doing science. The course has evolved over the years, but the scientific way of learning about the world, involving careful guided observation, and field experimentation characterize the work. Every Monday we do Creature Feature, in which I bring ten to fifteen specimens of a creature, perhaps starfish or horseshoe crabs and students are asked to observe and say as much as they can about what they observe. This is difficult at first. They start out by saying it has a claw or a shell, and only later do they become better at distinguishing characteristics of animals. Every Friday we do experiments in physical oceanography, examining waves, tides and salinity. One way we have investigated currents is by repeating Benjamin Franklin's experiment and inserting cards in bottles and dropping them in the ocean. Of the 2000 bottles that have been set adrift, about thirty have been returned from such diverse locations as Ireland, Scotland, Portugal, France, Sweden, Bermuda, Nova Scotia, and Ipswich.

Reading, writing, mathematics and history are integrated into the course. Each spring students collect data on herring migration, when herring, in a way somewhat similar to salmon, return to their birthplace to lay eggs. (Unlike salmon, herring don't die at the end of the process.) Students record the weight, length and sex for a sample of the herring, find the average for the data, and compare their findings with those recorded for previous years. One interesting finding has been that following the Blizzard of 1978, the 1979 herring catch had an average weight drop and a length increase!

Students conjecture why this might have occurred since during the blizzard the herring were many miles south of New England. Students also learn about one of the major commercial uses of herring as fertilizer, and that Indians also used herring for fertilizer, and that this saved the lives of many Pilgrims.

Students receive a monthly learning agenda that specifies all assignments, including homework. I tell them that they will get no surprise quizzes, no weekend homework, and in exchange, there are no excuses, work must be done on time.

I want to instill in my students that each one of them can make a difference. In 1976, one of my students wrote a letter to our congressman stating how precious Stellwagen Bank, an underwater shelf used as a habitat by local whale populations, is and recommending that it be declared a sanctuary. In 1992, that actually happened. My former student is now an officer in the merchant marine.

My overall emphasis is to treat this program as an attitude, not a course. We are related to the ocean, and the ocean profoundly affects our lives. Our chosen theme has been "Stewardship"-- building the sense of responsibility for the earth. Students learn that stewardship centers around being proactive and taking responsibility for their environment.

All human beings need a passion in their lives. I have found mine. When my students see there is a purpose to what they do in school, when they make connections between school and the world, their eyes light up and I hope that, maybe, they will get a sense of the excitement that can develop when one is committed to making a difference in events that affect the quality of all our lives.

-- George Kurlycheck, Harwich Middle School

We shall not cease from exploration

And the end of all our exploration

Will be to arrive where we started

And to know the place for the first time.

-- T. S. Eliot, "Four Quartets"

Instructional Resources and Materials

For many districts, realizing the vision of science and technology presented in this framework will take time, resources, collaborative planning and commitment. The numerous issues involved in systemic science and technology reform are addressed in Chapter 4 of common chapters, but some issues of particular relevance to science and technology education, including the need for appropriate facilities and materials, attention to safe practices, curriculum coordination and legal responsibilities are presented here.

Facilities and materials

Districts should work toward ensuring that students have the facilities and materials needed for undertaking 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 and technology.

Safe Practices in working with tools, materials and living organisms

Safety is a critical issue and an integral part of the teaching and learning of science and technology at all levels. It is the responsibility of each district to provide safety information and training. Fire extinguishers, safety glasses, eyewash stations, safety showers, utilities shutoff, appropriate waste containers, and first-aid kits should be readily accessible. Proper use of and care for tools is a crucial part of science and technology learning.

Biology teachers consider dissection to be an important educational tool as it provides students with real organisms. But dissection should be used with care. Teachers should recognize when animal dissection is considered that there are other experiences, i.e. 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."

Curriculum Coordination

It is important that a district's science and technology program be viewed as a whole so that the scope and sequence of the program from PreK through twelve is coherent. The district coordinator should be involved in articulating and coordinating district-wide (PreK-12) science and technology programming. In addition, science and technology 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.

Legal Issues

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

Partnerships Advancing the Learning of Mathematics and Science (PALMS)

Criteria for Evaluating Instructional Materials and Programs in Mathematics and Science and Technology

Why was this developed?

The following criteria -- Evaluating Instructional Materials and Programs in Mathematics, Science and Technology -- are recommended for use by Massachusetts educators.

These criteria are designed to help districts, schools and teachers to first, reassess the strengths and weaknesses of the programs and materials they have in place, and second, to assess the strengths and weaknesses of new programs and materials being considered for implementation.

The Massachusetts Department of Education does not choose to mandate specific programs, but rather to provide tools that will help professionals to select programs that best match the specific needs of their students.

Who is it for?

While the criteria are primarily for districts leaders, they also provide a useful guide for teachers as they reshape specific curriculum activities to align with the Curriculum Frameworks for Mathematics and for Science and Technology. These Frameworks, which are based upon the goals set forth in the Massachusetts Common Core of Learning, present a vision for the reform of mathematics, science and technology in the Commonwealth schools. The Frameworks also provide Guiding Principles, Habits of Mind and Content Standards, which are organized according to Core Concepts, Strands, Learning Standards, and Examples of Student Learning.

How are the criteria to be used?

The Curriculum Frameworks in Mathematics and in Science and Technology should be used in conjunction with the criteria. It is unlikely that a program will satisfy all components of the criteria. Reviewing published programs critically and becoming familiar with their particular strengths and weaknesses will help teachers and districts to make informed decisions about program selection, program modification and the use of supplementary materials.

These criteria are organized into six categories. These categories should be considered as overlapping rather than distinct. In evaluating programs and materials, it is recommended that the evaluating committee give special consideration to how all the components of the materials and programs work together to ensure that students' experiences in mathematics, science and technology are of the highest possible quality.

All Categories reflect the Vision, Guiding Principles, and Habits of Mind described in the Content Chapters of the Mathematics and/or the Science and Technology Curriculum Frameworks.

1. Mathematics, Science and Technology Content

- Reflects the Learning Standards in the Content Chapters of the Mathematics and/or Science and Technology Curriculum Frameworks.
- Is scientifically and mathematically correct and current.
- Incorporates real-world science technology and/or mathematics.
- Provides opportunities to show how a scientist, mathematician or technologist thinks.
- Reflects the diversity of our society through activities, use of language, and illustrations.

2. Organization and Structure

- Provides cohesive units, multi-day in length, that build conceptual understanding.
- Provides for in-depth, inquiry-based investigations of major scientific and mathematical concepts.
- Emphasizes connections among science domains technology and within mathematics.
- Emphasizes interdisciplinary connections.
- Incorporates appropriate instructional technology.
- Incorporates materials that are appropriate and engaging for students of the community.
- Includes a master source of materials and resources.
- Includes safety precautions where needed, and clear instructions on using tools, equipment and materials.

3. Student Experiences

- Emphasize students doing science technology or mathematics.
- Involve students in active, inquiry-based, open-ended learning, and problem solving.
- Involve use of manipulatives to explore, model and analyze.
- Involve use of instructional technology to visualize complex phenomena or concepts, acquire and analyze information, and communicate solutions.
- Provide multiple routes for students to explore concepts and communicate ideas and solutions.
- Are developmentally appropriate and provide for diverse cultural backgrounds, abilities and learning styles.
- Encourage collaboration and reflection.
- Have relevance to the students' day-to-day experiences.
- Use a variety of resources (e.g., trade books, measuring tools, information technology, manipulatives, primary sources and electronic networks).

4. Teacher Support Materials

- Provide background about the content.
- Offer ideas for how parents and community could be involved and kept informed about the program.

- Give suggestions for creating a variety of learning environments, such as cooperative learning; independent research; grouping strategies; student as teacher, learning enters and field trips.
- Reference resource materials such as appropriate videos, file clips, reference books, software, video laser disk, long-distance learning, CD ROM, electronic bulletin boards.
- Suggest how to adapt materials for different developmental levels of students.
- Incorporate strategies for engaging all students such as open-ended questions to stimulate student thinking, journals, manipulatives, explorations, visual, auditory and kinesthetic approaches.
-

5. Student Assessment Materials

- Are free of racial, cultural, ethnic, linguistic, gender, and physical bias.
- Are oriented toward problem solving and real world applications.
- Are embedded in the instructional program, occurring throughout the unit, not just at the end.
- Incorporate multiple forms of assessment such as: student demonstrations; oral and written work; student self-assessment; technology; teacher observations; individual and group assessments, and journals.
- Focus on the process of learning such as: predicting; modeling; making inferences; and reasoning (not just the product).

6. Program Development and Implementation

- Was designed using a research base.
- Has evidence of effectiveness, such as field test data regarding impact on student learning, behavior, and attitudes, including underrepresented student populations.
- Is flexible and adaptable to local curriculum and/or school.
- Offers training, sustained technical assistance, and long-term follow-up for teachers.

References

Association of State Supervisors of Mathematics and National Council of Supervisors of Mathematics. Guide to Selecting Instructional Materials for Mathematics Education. Mountain View, CA: Creative Publications, 1993.

California Department of Education. "Instructional Materials Criteria." Science Framework for California Public Schools. Sacramento, CA: California Department of Education, 1990.

____. "Instructional Materials Criteria." Mathematics Framework for California Public Schools. Sacramento, CA: California Department of Education, 1992.

National Science Resources Center. Criteria for Evaluating Elementary Science Curriculum Materials. Washington, DC: National Academy of Sciences.

Ralph, J. and Dwyer, M.C. Making the Case: Evidence of Program Effectiveness in Schools and Classrooms, Criteria and Guidelines for the U.S. Department of Education's Program Effectiveness Panel. Washington, DC: U.S. Department of Education, Office of Educational Research and

Improvement, 1988.

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American Association for the Advancement of Science, Project 2061. (1993). Benchmarks for Science Literacy. New York: Oxford University Press.

Baron, J.B. (1990). Performance Assessment: Blurring the edges of assessment, curriculum and instruction. In A. Champagne, B. Lovitts and B. Calinger (Eds.), Assessment in the Service of Instruction. Washington, D.C.: American Association for the Advancement of Science.

Biological Sciences Curriculum Study. (1995). Redesigning the Science Curriculum. Colorado Springs, CO.

Carl Perkins Act (1990). U.S. Congress Carl D. Perkins Vocational Education Act (P.L. 98-524).

Carson, R. (1962). Silent Spring. Boston: Houghton Mifflin.

Commonwealth of Massachusetts, Department of Education. (1990). Common Competencies: The promise of linguistic and cultural diversity, pp. 30-31.

Commonwealth of Massachusetts, Department of Education. (June 1994). Eliminating the General Track, background paper.

Department of Education and Science. (1995). Science in the National Curriculum, London: Her Magesty's Stationery Office.

Duckworth, E. (1987). The Having of Wonderful Ideas and other essays on teaching and learning. New York: Teachers College Press.

Hayes, I. Twisting the dragon's tail, Washington Science Teacher's Journal, November 1993, pp. 7-10.

Kelley, J. and K. Skelly (Eds.) (1994). Teachers' Investigations in Alternative Assessments. University of Lowell.

Komacek, S., Lawson, A., and Horton, A. (1990). Manufacturing Technology. Albany, N.Y.: Delmar.

Komacek, S. (1993). Production Technology. Albany, N.Y.: Delmar.

LaPorte, J., and Sander, M., Integrating Technology, Science and Mathematics in the Middle School, The Technology Teacher: (March 1993). Reston, VA.: International Technology Education Association.

Loucks-Horsley, S., et al. (1990). Elementary School for the 90's. Andover, MA: The NETWORK.

National Center for Improving Science Education. (1991). The High Stakes of High School Science. Andover, MA: Author.

National Research Council. National Science Education Standards: Draft November 1994. Washington, D.C.: Author.

National Science Teachers Association. (1992). Scope, Sequence and Co-ordination of Secondary School Science. Volume I- The content core. Washington D.C.: Author.

New York State Education Department. (1994). Framework for Mathematics, Science, and Technology. Albany, NY.

NGS Kids Network. (1991). Too Much Trash? National Geographical Society.

O'Brien-Carelli, A., and Kelly, B. Curriculum, Instruction and Assessment.

Phillips, K. (1991). Developing A Technology Education Program. Glenn Ellyn, IL.: Technical Foundation of America.

Raizen, S, (ed.), Sellwood, P., Todd, R., and Vickers, M. Technology in the Classroom: Understanding the Designed World, forthcoming, Jossey Bass.

Richards, R. (1990). An Early Start to Technology. London: Simon and Schuster.

Rutherford, J.and Ahlgren, A. (1989). Science for All Americans: A project 2061 report on goals in science, mathematics and technology. Washington, D.C.: American Association for the Advancement of Science.

Savage, E., and Sterry, L. (1990). A Conceptual Framework for Technology Education. Reston, VA.: International Technology Education Association.

Smith, H. Exploring Energy Sources/Application Alternatives. South Holland, IL.: Goodhart, Wilcox.

Solomon, J. and Aikenhead, G. (1994). STS Education: International Perspectives on Reform. New York: Teachers College Press.

Technology A National Imperative: National Technology Education.

Advisory Council. (1988). International Technology Education Association. Reston, VA.

Wheelock, A. (1992). Crossing the Tracks: How untracking can save America's schools. Dexter, MI: The New Press.

Wright R. T. (1993). Manufacturing in Technology Education. Glencoe Peoria, IL.

Wright, R., Israel, E., and Lauda, D. (1993). Teaching Technology -- A Teacher's Guide. Reston, VA:

International Technology Education Association.

Wright, R., Israel, E., and Lauda, D. (1993). A Decision Maker's Guide to Technology Education, Reston, VA: International Technology Education Association.
