PIEE
AT ELM PARK AND MIDLAND STREET ELEMENTARY SCHOOLS

An Interactive Qualifying Project Report

Submitted to the faculty of the

WORCESTER POLYTECHNIC INSTITUTE

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1. PIEE
2. Lesson Plans
3. Midland St. School
4. Elm Park Community School

Abstract

The Partnerships Implementing Engineering Education program, sponsored by the National Science Foundation, is dedicated to integrating engineering into school science programs. The IQP team worked with the Worcester Public School system to develop engineering lessons, for five fourth grade classrooms, according to the Massachusetts Science and Technology/Engineering Curriculum Frameworks and the Worcester Public School Benchmarks. The IQP team assisted the teachers with lesson implementation. To judge each lesson's effectiveness the IQP team developed a feedback rubric for the teachers' feedback.

Acknowledgements

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I
Executive Summary

"A poor surgeon hurts 1 person at a time. A poor teacher hurts 130." (Ernest Boyer) In a society based on technology and engineering, it is important for students to learn this subject matter effectively to become informed citizens of society, and to have a strong educational base for those who seek higher education in these fields of study.

Ideally, all students in the Worcester Public School System (WPS System) would come from homes that aid their academic learning experience. This has been proven to encourage students to do well in school, and therefore students who come from strong academic backgrounds receive some form of higher education, and poverty rates are lower in cities with a highly educated work force. This leads to a better quality of living for all members in the community, and a higher quality of living is the ultimate goal for anyone. (Darby, Michael, 1996)[9] In the city of Worcester, there is a high poverty rate with about 14.1% of the population living in poverty. (Wikipedia, 2000) [20]

There are a variety of problems in the Worcester Public School system (WPS). Low scores on the Massachusetts Comprehensive Assessment System (MCAS) is just one of the issues that the WPS System faces. The team will attempt to find a better way to teach the subjects engineering, science and technology to the 4th grade classrooms in two different schools. In order to adequately assess the problems associated with the project, the team has researched various topics. These topics include, but are not limited to: The Worcester Public School System, how Worcester varies from the state in MCAS scores, and other programs that are being conducted around the country to solve the same problem. By studying the Worcester Public School System through observation, the team has discovered the best way to aid students in their learning by making lessons appropriate to their learning outcomes.

In order to solve the problem of low test scores on the MCAS, the WPI team has created a variety of lesson plans to teach the students the material as set by the WPS Benchmarks and Massachusetts Frameworks. All of the lessons in the report follow these standards. The team used a variety of methods to perfect the lesson plans. First the team chose different aspects of the Benchmarks and Frameworks and assembled lessons based on personal knowledge and outside sources. The lessons then went to the Graduate Fellows and advisor for review, until a final draft was completed. At this point, the lessons were acceptable to use in the classroom at Midland St School and Elm Park Community School. After the lessons were implemented, the teachers at the two schools completed assessment forms. After the assessment forms were completed, the students adjusted the lessons to the teacher recommendations.

From the project, the schools seem to be better off in terms of their methods of teaching engineering, science, and technology. Without these lessons, few teachers appeared to be well prepared to teach these subjects. From the project, we aspire to assist the Elm Park and Midland schools achieve higher scores on the MCAS testing system.

The project has achieved many goals. From the IQP student's point of view, they have learned the challenges that face American school teachers. They now have a higher appreciation for those that spend their days teaching young minds to become citizens of the society. As for the teachers, they are appreciative of the program that has made a difference in their lives and the lives of the children that they teach.

II
A
Massachusetts Frameworks

The purpose of science and technology in elementary education is to develop investigative skills and habits. Students are educated with the assumption that they will pursue further education in the science and technology field after high school (The Commonwealth of Massachusetts Department of Education (Mass DOE), 2001) [4]. If a student does not pursue such an education, they still have acquired valuable investigative and design skills (Mass DOE, 2001) [4].

The Massachusetts Science and Technology/Engineering Curriculum Frameworks present a guideline for all of the Commonwealth of Massachusetts public schools. The frameworks are meant to help educators statewide strengthen their technology and engineering curriculum (Mass DOE, 2001) [4].

History

The Education Reform Act of 1993 started an initiative to develop statewide educational standards. One of several objectives set forth by the reform was to develop and implement a science and engineering curriculum frameworks. In 1995, the first framework was approved (Mass DOE, 2001) [4].

Since the field of science and technology is ever changing and always presents new challenges, a revision panel was appointed in 1998. This panel was also a mandate set forth by the Reform Act. The panel reviewed the progress of the frameworks that was implemented in 1995 and started to make revisions. The current frameworks were drafted in 1999 and approved in 2001 (Mass DOE, 2001) [4].

The frameworks were created and edited by many professionals in the field of pedagogy. The time and effort the professionals devoted to the development of the frameworks shows spectacular support for the advancement of public education (Mass DOE, 2001) [4].

Students in grade four should attain several skills of inquiry during this period of their education. They should be able to properly collect, record, and analyze data. They should be able to draw conclusions from such experiments and communicate their findings by writing reports and or making visual aides. The students should also be able to make predictions and work with appropriate tools such as scales and calculators (Mass DOE, 2001) [4].

Guiding Principles

The guiding principles are the ten commandments of Massachusetts public education. They are the ideals by which educators should form their classroom environments. These ten principles define the purpose of science and technology in the Massachusetts curriculum (Mass DOE, 2001) [4]. The principles are as follows:

1. A comprehensive science and technology/engineering education program enrolls all students from PreK through grade 12 (Mass DOE, 2001) [4].
2. An effective science and technology/engineering program builds students' understanding of the fundamental concepts of each domain of science and their understanding of the connections across these domains and to basic concepts in technology/engineering (Mass DOE, 2001) [4].
3. Science and technology/engineering are integrally related to mathematics (Mass DOE, 2001) [4].
4. An effective program in science and technology/engineering addresses students' prior knowledge and misconceptions (Mass DOE, 2001) [4].
5. Investigation, experimentation, and problem solving are central to science and technology/engineering education (Mass DOE, 2001) [4].
6. Students learn best in an environment that conveys high academic expectations for all students (Mass DOE, 2001) [4].
7. Assessment in science and technology/engineering serves to inform student learning, guide instruction, and evaluate student progress (Mass DOE, 2001) [4].

8. An effective program in science and technology/engineering gives students opportunities to collaborate in scientific and technological endeavors and communicate their ideas (Mass DOE, 2001) [4].
9. A coherent science and technology/engineering program requires district-wide planning (Mass DOE, 2001) [4].
10. Implementation of an effective science and technology/engineering program requires collaboration with experts, appropriate materials, support from parents and community, ongoing professional development, and quantitative and qualitative assessment (Mass DOE, 2001) [4].

Strands

The curriculum is broken down into four main areas of study called strands. The strands are a method used by the department of education to organize educational content. These strands set the standard for what students should know and have the ability to perform at the end of each grade. The four strands are earth and space science, life science, physical sciences, and technology/engineering (Mass DOE, 2001) [4].

Earth and Space Science:

Students in grade four primarily focus on earth materials, weather, water, and the solar system. The first topic is Rocks and Their Properties. They learn to categorize rock, for example, whether it is metamorphic or sedimentary. The second topic is Soil. Students learn about the origin of soils, and they discuss their different properties. Teachers can opt to undertake the design and construction of a compost bin with their class. The third topic is Weather. Students learn about precipitation, global patterns and jet streams, weather vs. climate, and how air temperature, moisture and wind speed affect the weather. Students are encouraged to design and build several instruments to measure the weather. The fourth topic is Water Cycle. Students learn how water cycles through our environment and how it affects the weather. Building terrariums in class is encouraged as a lesson extension. The fifth topic is Earth’s History. Students learn how the weather affects the surface of the earth e.g. erosion, and earthquakes. The sixth and final topic is Earth in the Solar System. The planets, sun and moons are taught to be a system, and that the earth is a part of that system. The earth revolves around the sun, and the moon changes its shape (Mass DOE, 2001) [4].

Life Science:

Students in grade four primarily focus on plants and animals, adaptation, and how energy relates to living things. The first topic is Characteristics of Plants and Animals. They learn to classify plants and animals into categories by analyzing their physical traits. The second topic is Plant Structures and Functions. Students learn about plants and their process of gathering food and water, and the method plants use to reproduce. They learn about the birth, development, reproduction, and death of animals. They learn the difference between characteristics that are inherited and those that are a result of the animal or plant's environment. The third topic is Adaptations of Living Things. Students learn how certain inherited traits change over several generations depending on how the environment affects that plant or animal. They learn how environmental conditions cause migration or death. They learn about organisms' patterns and behaviors, and how those behaviors are affected by harsh conditions and seasons. The fourth and final topic is Energy and Living Things. Students learn and discuss how plants use the energy from the sun to make sugar e.g. photosynthesis. They also learn about the transfer of energy from producers to consumers to decomposers (Mass DOE, 2001) [4].

Physical Sciences:

Students in grades three through five primarily focus on matter, electrical energy, magnetic energy, sound energy, and light energy. The first topic is Properties of Objects and Materials. Students learn about properties of materials such as color and texture and about the properties of objects such as size and shape. The second topic is States of Matter. Students learn the basics about solids, liquids, and gas. They also learn about condensation, evaporation, freezing, and melting and how it affects the properties of water. The third topic is Forms of Energy. Students learn about the five basic forms of energy: electric, magnetic, light, heat, and sound. They also learn how one form of energy can be transformed into another. The fourth topic is Electric Energy. Students study circuits and electrical current. They learn to group materials based upon their conductivity. Students also learn the theory and practice behind electromagnetism. The fifth topic is Magnetic Energy. Students learn about polarity, and what materials are ferrous. The sixth topic is Sound Energy. Students learn about vibrations and how they resonate through different materials. Students can use tuning forks to see how the rate of vibration affects the pitch. The seventh and final topic is Light Energy. Students learn how light travels, and how it is absorbed, refracted, and reflected (Mass DOE, 2001) [4].

Technology/Engineering:

Students primarily focus on how science and technology can be used to solve engineering problems. This category is very loosely defined. The Engineering Design Process is the center for the curriculum. Grade four deals with how materials, tools, and machines can solve problems in daily life. They learn to recognize, assess solutions to, and create a solution to a problem. (Mass DOE, 2001) [4].

II
B
Worcester Public Schools Benchmarks

Science and technology is a growing educational field in the United States. For about 10 years, the Worcester Public Schools have been implementing engineering as part of the curriculum in order to guide students into the future of technology. With the implementation of engineering, a child can have hands-on experience using their mental and physical skills in order to educate themselves in this growing age. The Worcester Public Schools have created a set of benchmarks to act as a guide so that all of the teachers in the 40+ elementary schools in Worcester will be on the same level in their teaching. The benchmarks are a tool for teachers to provide students from the 40 different schools a similar education. Along with other subject areas, these benchmarks include the implementation of engineering within the curricula. (http://www.wpsweb.com/science/wpscur.htm#mission_statement (WPS2), 2004) [19]

The following excerpt is from the Worcester Public Schools website referencing the importance of education in technology.

> *"The mission of the Worcester Public Schools mathematics, science and technology curricula is to provide equal opportunities for all students to discover the power of mathematics, science and technology. In conjunction with Goals 2000, National Council for Teachers of Mathematics Curriculum and Evaluation Standards, the Massachusetts Common Core of Learning and State Frameworks, this curriculum will be a teacher's reference for instructional strategies. This curriculum provides solid content and materials that will enable teachers to develop a community of life-long learners and problem solvers."*(WPS2, 2004) [19]

The benchmarks consist of five major subjects including: Skills of Inquiry, Earth/Space Science, Life Science, Physical Science, and Technology/Engineering. Each subject is broken down into individual requirements that a teacher must implement. The teachers will then develop lesson plans based on these requirements and teach them throughout the school year. Every grade level has a certain criteria of engineering which will coordinate with their level of intellectual growth. Starting from a broad field of technology/engineering, the students will progressively learn more acute fields as they mature through school. These benchmarks are used to set the standard education that is vital to the child's developing intelligence. (WPS2, 2004) [19]

The State of Massachusetts has developed curriculum frameworks in correlation with the increasing demand of technology in the United States. The *Massachusetts Common Core of Learning and State Frameworks* has provided a concrete template curriculum on which the benchmarks are based. (WPS2, 2004) [19]

These benchmarks have been part of the Worcester Public School System for 10 years and have been a guideline for the education of the students. The importance of this implementation of engineering can only increase due to the increasing demand of new technology. The curriculum can easily adapt to the rapid growth of technology in the world and the benchmarks can always set the standard. (WPS2, 2004) [19]

II
C
The Worcester Public School System

Every school system has a specific structure. In a small town, a school system may contain only an elementary school and a high school. If the town is a little bigger, there may be a separate middle school or the choice of a vocational high school. Because the population of Worcester is so large, the Worcester Public School System is made up of many schools around the city. The city is divided into four districts and governed by one school committee. The Worcester Public Schools and its structure are unique in many ways. (http://www.wpsweb.com/ (WPS), 2004) [18]

The Worcester Public School System is divided into four sections called quadrants. The quadrants are North, South, Burncoat and Doherty; named after their respective high schools. Elementary schools contain children ranging from kindergarten to the sixth grade. There are about forty elementary schools in the city; however, this number changes as new schools are built and old schools close down. Amongst the elementary schools in the city, there are some that specialize in certain areas. For example, Worcester Arts Magnet School (WAMS) is a school that specializes in the arts and The Goddard School of Science and Technology specializes in science and technology. (WPS, 2004) [18]

There are four middle schools in the city of Worcester. Middle schools encompass grades 7 and 8 and provide a transition for the students into high school. This stage in school is used to prepare the students to deal with the balance of both school work and communication with their peers so that high school does not overwhelm them. The middle schools in the Worcester Public School System are named Worcester East Middle School [North Quadrant], Sullivan Middle School [South Quadrant], Forest Grove Middle School [Doherty Quadrant] and Burncoat Middle School [Burncoat Quadrant]. After middle school, the children go to the high school in their respective quadrant. (WPS, 2004) [18]

High school is the final step in obtaining a diploma from the city of Worcester. Although there are only four quadrants, there are six high schools. This discrepancy comes from the fact that Worcester also offers a vocational high school and a high school concentrating in science. Worcester Vocational High School and The Advanced Learning Laboratory are options given to students who have different aims in life. Any student in the city can attend these school based on what they aspire to do with their life, but for the most part, students go to their respective district high school. There is also Worcester Alternative, which is not listed in the number of high schools but is a school that provides a second chance for students that have troubles adjusting to high school. (WPS, 2004) [18]

II
D
Massachusetts Comprehensive Assessment System

The Massachusetts Comprehensive Assessment System (MCAS) was created in May, 1998 to help the state of Massachusetts test schools on whether or not they are fulfilling the state requirements. This statewide exam was created for fourth grade, eighth grade, and tenth grade. It tests students in English Language Arts, Mathematics, and Science & Technology. These tests help the state keep track of which schools are following the new Education Framework of 1993. The MCAS tests measure the performance of students, schools, and districts on the academic learning standards contained in the Massachusetts Curriculum Frameworks. The state believed they could set a new high academic standard for all other states to follow.

The very first MCAS test, given in 1998, was the beginning for all other MCAS tests to be compared to. With a standard to compare all schools against, the Massachusetts Board of Education could measure improvements towards the state requirements at each individual school. In the first couple of years that the MCAS was implemented, many schools were not ready to change their curriculum to meet the state requirements. Many schools fought with the state's Board of Education to change the material being tested on the MCAS. In the beginning of MCAS testing, many schools were not prepared for the tests because of the late change to the new state regulations. The first test given was challenging for the students who took it because of the lack of preparation and knowledge of the material given on the exam. Massachusetts' Board of Education made sure that nearly all students in the state had to take this exam, very few were exempt. The reason why so many students could not be excused from the MCAS was based on the fact that the tenth grade results were a graduation requirement. One of the regulations on the MCAS tests is that all students must have been enrolled in regular education programs. Students with disabilities are not exempt from taking the exam. This statewide test was not limited to just public and private schools. Students enrolled in charter schools were also made to take these tests. Also, the students receiving publicly funded special education in 766-approved private schools must take the MCAS. Any and all students in vocational or institutional schools must also take the test, as well as any students in educational collaboratives. The people who were exempt from the exam are all students that do not fit into the guidelines and rules stated above. The MCAS was, for a while, only produced in English and this meant that students with limited English proficiency were still required to take the exam. This limitation on language only lasted a short amount of time.

The Board of Education decided that there should be an alternate test for students not competent in English. This excerpt discusses what came about for people that had English as their second language.

> " An alternative assessment offered to limited English proficient (LEP) students in 1998 was a Spanish-language version of the state-developed MCAS tests in Mathematics and Science & Technology. The Spanish language version was developed because approximately 60% of the LEP students in Massachusetts are native Spanish speakers. Eligibility to participate in the Spanish-language version of MCAS was restricted to LEP students who, in May of 1998, met all of the following requirements:

- The student had completed three or fewer years of school in the United States; and
- The student was currently enrolled in a TBE program or received ESL support and would not be recommended for regular education classes for the following school year; and

- The student did not have adequate English-language skills to participate in the English-language version of MCAS; and
- The student possessed reading and writing skills in Spanish appropriate to his or her grade level. (Massachusetts Department of Education, State Government)[7] "

Spanish was the first alternate language offered for the MCAS to be taken in. Even though they were in different languages, both tests had the same types of questions and the same scoring.

There were four different types of questions: multiple choice response questions, short answer questions, open response questions, and long and short compositions. The scores accumulated from these types of questions would place you into specific groups, which helped the state understand how proficient you were in each curriculum. Students receive reports on their scores with the classifications of advanced, proficient, needs improvement, and failing. This type of classification is different than most standard exams given in schools across Massachusetts. These results given back to the students were given in ranges of scores and not as exact numbers.

These divisions of students into groups based on their grades were a point of conflict for many schools. Another point of conflict between school and the Board of Education was the requirement that all students must pass the tenth grade MCAS to graduate. With the addition of the requirement for students to pass the MCAS to graduate, schools now offer remedial programs to help students pass the MCAS. This also meant that schools had to offer the MCAS more than once a year for tenth graders that did not pass it the first time. Many teachers believed that the MCAS tests took away from material that students should have been learning. This argument was also expressed from parents and students that had to cope with the exam. Many schools and teachers protested the taking of the exam; some schools still protest the taking of the MCAS exam.

Another big problem that many parents disagreed with was the availability of MCAS grades to colleges and schools outside of their districts. Many students do not perform to their capability on this exam because of the style that the test is presented in.

The MCAS testing in Massachusetts started off as a means of keeping schools up to a high standard of education, while now the state is turning the test into a means of grading students on a higher level. Massachusetts' Board of Education felt it needed an exam to see how each student compared when it came to certain pertinent material (Massachusetts Department of Education, State Government), similar to the regency exams given out in New York schools. The MCAS testing has become one of the staple examples of the Massachusetts educational system because of its impact on students and schools.

After reviewing all the information provided to the IQP team it became obvious that Worcester Public Schools were lacking in their performance on the MCAS tests. Specifically when looking at the scores provided for the fourth grade students in Worcester. The most disturbing fact that came from the results of last years MCAS test was that overall most students were in the needs improvement or in the warning/failing category. The results showed that students in the Worcester Public School system, specifically the fourth grade need more engineering and design lesson plans.

II
E
The Profile: Worcester vs. Massachusetts

The Massachusetts Department of Education puts out a “profile” for every school district in the state every year. These profiles inform the public of different things pertaining to each school district comparing it to the state overall. It gives insight on things like general student/teacher information, testing results and finances. All information was gathered in between the years 2002 and 2004. (Massachusetts Department of Education (DOE), 2004) [6]

In the category of enrollment by race/ethnicity, the Worcester School District had a higher percentage of all minorities and a lower percentage of white students which is shown in Table II.E.1.

Table 1: Enrollment by Race/Ethnicity

Race	% of District	% of State	Ratio Dist/State
African American	12.20	8.80	1.39
Asian	8.20	4.70	1.74
Hispanic	30.80	11.50	2.68
Native American	0.60	0.30	2.00
White	42.80	74.60	0.57

The ratios show that the schools in Worcester are more culturally diverse than other schools in the state. (DOE, 2004) [6]

The following table shows enrollment by gender:

Table 2: Enrollment by Gender

	District	State	Ratio Dist/State
Male	12,921	504,745	N/A
Female	12,134	476,073	N/A
Total	25,055	980,818	.03
Ratio M/F	1.06	1.06	1.01

The male to female ratio in Worcester is almost even. The difference of the male to female ratio in the Worcester School District to the state is so close to 1 that it is negligible when drawing any conclusions between Worcester and Massachusetts. (DOE, 2004) [6]

In selected populations, Worcester has a higher percentage in all of the categories as shown by Table II.E.3.

Table 3: Selected Populations

Title	% of District	% of State	Ratio of Dist/State
English Second Language	35.80	13.70	2.61
Limited English Proficient	13.50	5.00	2.70
Low-income	60.40	27.20	2.22
Special Education	18.30	15.60	1.17

Worcester is similar in the amount of special education students they have, however, they are still at a higher percentage than the state. Worcester has double and in some cases over two and a half times the percentage of children as the state in the other three areas. (DOE, 2004) [6]

For the percentage of children attending public schools, the following table is shown.

Table 4: Children Attending Public Schools

	% of District	% of State	Ratio Dist/State
Children Attending Public Schools	88.70	89.80	0.99

We see that there is a smaller percentage of children attending public schools in Worcester compared to the state. This does not mean that more children have dropped out of high school; rather, it means there are more children enrolled in private schools in Worcester. (DOE, 2004) [6]

Indicators are items such as dropout, attendance, suspension and retention rates. The "indicators" for Worcester and the state are in Table II.E.5.

Table 5: Indicators

Indicator	District	State	Ratio Dist/State
Grade 9-12 Dropout Rate	5.10	3.30	1.55
Attendance Rate	93.90	93.90	1.00
In-School Suspension Rate	8.70	4.60	1.89
Out-of-School Suspension Rate	10.00	6.70	1.49
Retention Rate	4.00	2.60	1.54
Exclusions rate per 1000	4.10	2.00	2.05

Although the attendance rate is equal to the states, everything else is at least 50% lower than the state normal. (DOE, 2004) [6]

In the area of technology, it is shown that even though the Worcester School District has fewer computers per student than the state, the computers are more readily available because they are in every classroom.

Table 6: Technology

	District	State	Ratio Dist/State
Students per Computer	3.50	4.30	0.81
Classrooms with the internet [%]	100.00	93.00	1.08

(DOE, 2004) [6]

The future plans of High School Graduates vary (See Table II.E.7).

Table 7: Plans of High School Graduates

Plan	% of District	% of State	Ratio of Dist/State
4-Year Private College	21.00	31.00	0.68
4-Year Public College	26.00	25.00	1.04
2-Year Private College	2.00	2.00	1.00
2-Year Public College	29.00	17.00	1.71
Other Post-Secondary	3.00	2.00	1.5
Work	9.00	12.00	0.75
Military	3.00	2.00	1.50
Other	2.00	1.00	2.00
Unknown	7.00	8.00	0.88
Total Secondary Education	81.00	77.00	1.05

There is not a significant difference in the total secondary education, and 4-year public/2-year private are similar as well. There is a less than average direction toward 4-year private, however, a much greater than average direction toward 2-year public college. (DOE, 2004) [6]

Another important part of education is those providing it.

Table 8: Teacher Data

	District	State	Ratio Dist/State
Total # of Teachers	1,892	72,062	0.03
% of Teachers Licensed in Teaching Assignment	93.3	93.9	0.99
Total # of Teachers in Core Academic Areas	1,512	59,662	0.03
% of Core Academic Teachers Identified as Highly Qualified	92.40	93.90	0.98
Student/Teacher Ratio	13.2/1	13.6/1	0.97

This table shows that the numbers for the teachers in Worcester compared to those of the state are extremely close. There are a slightly smaller number of licensed teachers; however, the student/teacher ratio is slightly better. Comparing this table to table to Table 2 we find that there are the same percent of teachers in the Worcester compared to the state as there are students putting it on par with the state average. (DOE, 2004) [6]

MCAS testing is also an important part of the education process in Massachusetts because it is required for graduation. The following table shows the percentage of students in the different performance levels of each subject.

Table 9: MCAS Tests of Spring 2004 Percent of Students at Each Performance Level

	Advanced			**Prof.**		
Grade and Subject	District	State	Ratio Dist/State	District	State	Ratio Dist/State
3-Reading	N/A	N/A	N/A	39	63	0.62
4-Enlish Language Arts	4	11	0.36	29	45	0.64
4-Mathematics	4	14	0.29	17	28	0.61
5-Science and Tech.	8	20	0.40	21	35	0.60
6-Mathematics	9	17	0.53	19	25	0.76
7-Enlish Language Arts	3	9	0.33	36	59	0.61
8-Mathematics	3	13	0.23	11	26	0.42

8-Science and Tech.	1	5	0.20	11	28	0.39
10-Enlish Language Arts	7	19	0.37	30	43	0.70
10-Mathematics	11	29	0.38	19	28	0.68

Table 10: MCAS Tests of Spring 2004 Percent of Students at Each Performance Level (cont.)

	Need Imp.			**Warn/Fail**		
Grade and Subject	District	State	Ratio Dist/State	District	State	Ratio Dist/State
3-Reading	48	30	1.60	13	7	1.86
4-Enlish Language Arts	48	35	1.37	20	9	2.22
4-Mathematics	49	44	1.12	30	14	2.14
5-Science and Tech.	44	33	1.33	27	13	2.08
6-Mathematics	31	32	0.97	41	25	1.64
7-Enlish Language Arts	40	25	1.60	21	7	3.00
8-Mathematics	29	32	0.91	57	29	1.97
8-Science and Tech.	27	35	0.77	61	31	1.97
10-Enlish Language Arts	39	27	1.44	24	11	2.18
10-Mathematics	34	28	1.21	36	15	2.40

Worcester is below the state average for the percent of students in the categories of advanced and proficient for all subjects. They have higher percentages in the needs improvement category for all but three subjects. In the lowest category, which is Warning/Failure, the Worcester School District has very high percentages usually more than doubling the statewide percentage rate, and in one subject, tripling it. (DOE, 2004) [6]

The last portion of the profile focuses on finances. Table II.E.11 shows the expenditures per student.

Table 11: Per Pupil Expenditures

	District	State	Ratio Dist/State
Regular Education	6,209	6,779	0.92
Special Education	12,762	13,542	0.94
Bilingual Education	11,070	8,936	1.24
Occupational Day Education	10,982	11,154	0.98
All Day Programs	7,962	8,273	0.96

Worcester spends slightly less per student in every portion of education except for bilingual education where almost 25 percent more is spent. (DOE, 2004) [6]

Finishing up the finances, the profile gives us the average teacher salary for 2003, shown in the following table.

Table 12: Teacher Salaries and Counts

	District	State	Ratio Dist/State
Average Salary	51,666	51,803	0.997355366

The teachers in Worcester make slightly less that the teachers in the rest of the state but not really a significant amount less. (DOE, 2004) [6]

The Profile gives an excellent view into the demographic of the Worcester School District as compared to the state of Massachusetts in many areas. This also provided the IQP team with a statistical look into the Worcester school system. Though these statistics show how Worcester compares to the state it does no show how each school compares to the others in the state. The conclusion of the team found that the ability to teach engineering effectively depends on the classroom environment, not a district comparison.

II
F
NSF Proposal

With a large percentage of minority students in the Worcester Public School System, and a lack of these students seeking higher education in science, technology, or engineering, it is imperative that these students become interested in these subject fields at a young age. (Nicoletti, D, 2002) [11] The Projects Implementing Engineering Education [PIEE]'s goal is to facilitate teaching children an engineering, science and technology curriculum, based on the Massachusetts Science and Technology/Engineering Curriculum Framework [MSTECF, Frameworks].

The project began un-officially with Camp Reach, a program co-designed by Professors Denise Nicoletti and Chrysanthe Demetry to keep the interest of middle school aged girls in science and math. Camp Reach was originally funded by the NSF, so it seemed clear to Prof. Nicoletti, the organizer of the PIEE program, to seek financial assistance from the NSF once again.

PIEE attempts to achieve several goals through this program. There are four main goals in the program. The first is to institute the MSTECF in the Doherty quadrant of the Worcester Public School System. The Doherty quadrant was chosen because of its lack of programming relating to engineering and technology, and because the elementary teachers know that their students will be participating in programs that include engineering and technology in their subsequent learning experiences. The second main goal of the program is to assist in teacher preparation of implementing the MSTECF. Other goals of the project are to develop partnerships between teachers, students, and fellows[1] so that a model may be developed for other programs that may be seeking to fix a similar problem, and to develop a curriculum that may be used throughout the state with a similar environment such as the Doherty quadrant.

The project will span for three years, for grades Kindergarten through sixth, and be developed at three or more schools. For the first year, grades four, five, and six will have one team each. A team will consist of two graduate fellows, three P-Teachers[2], one IQP team, and a faculty advisor. This team will be called an "Initiation Team". The second year will branch out to another school. This school will have an "Adaptation Team". The team will be similar to the year-one team, but will be adapting the curriculum as needed. An "Initiation Team" will commence at the year one school with a similar team, but will be focused on grades two and three. The third year will branch to a third school. This school will have a "Sustainability Team". This team will transmit the year-one/year-two curriculum to other schools. An "Adaptation Team" will work with the year-two school in grades two and three, and an "Initiation Team" will work with grades Kindergarten and first in the year one school. (Please refer to Table II.F.1) There will also be summer workshops to prepare the teachers for the curriculum in the school year, and for the fellows/IQP students to gain feedback from the teachers what topics would be appropriate for their classrooms. The summer workshops in following years will be a vehicle for transmission of the curriculums and as an orientation to new members of the project. (Nicoletti, D, 2002) [11]

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[1] Fellows are students at WPI appointed to work on the project in exchange for financial aid and providing further study on the project.
[2] P-Teachers are the WPS teachers working in teams, and are a sub-set of the general body of teachers in the WPS system.

Table 13: Team Setup for the Project

Year	Group Name	Grades	Number of Teachers per Grade	School	Number of gP-Fellows** per Grade	Number of uP-Fellows** per Grade	Number of IQP Students per Grade	Number of Faculty Advisors per Grade
1	Initiation Team	4, 5, 6	3	1st	2	0	2 or 3	1
2	Initiation Team	2, 3	3	1st	2	0	2 or 3	1
	Adaptation Team	4, 5, 6	3	2nd	1	1	2 or 3	1
3	Initiation Team	K, 1	3	1st	2	0	2 or 3	1
	Adaptation Team	2, 3	3	2nd	1	1	2 or 3	1
	Sustainability Team *	4, 5, 6	3	Quadrant	0	1	2 or 3	1

* Sustainability team will consist of either an uP-fellow, or an IQP team.

** gP-Fellows and uP-Fellows signify graduate and undergraduate student fellows respectively.

The National Science Foundation has granted PIEE $1,081,764 (estimate) for three years. This will allow for 6 Graduate Fellows, and 0-6 Undergraduate Fellows per year.

II
G
National Science Foundation Funded Programs

The National Science Foundation funds many programs that are used to help teach young students about engineering. There are some programs that are only offered in Massachusetts, along with many others that are only offered out-of-state. All of the programs offered by the National Science Foundation (NSF) receive money from their respective states to fund the programs for schools. The programs that are more pertinent to this project are for students in grades kindergarten through sixth grade. Some of the programs in Massachusetts are located at schools such as Boston University, Harvard University, University of Massachusetts Amherst, Tufts University, University of Massachusetts Boston, and Northeastern University. As for the programs located at schools out of the state there is the University of Oklahoma, University of Maine, and the last out of state school is Syracuse University. These programs offer similar topics for younger student to learn. Each program gives a different perspective on mathematics, science, and technology.

One of the programs sponsored by the NSF is “Project STAMP -- Science Technology and Mathematics Partnerships”, which is being done by Boston University. The program offered at Boston University has graduate fellows from the Biology, Physics, Chemistry, Medicine, and Engineering Departments teach grades from sixth to twelfth. They teach classes in the suburban areas of Boston including Newton and Quincy schools. Some of the partners to this program are companies such as the Museum of Science Boston, the New England Aquarium, the optics company Melles Griot, and the

New England Board of Higher Education. Project STAMP's more interesting lessons have themes that deal with investigation, experimentation, and problem solving. Their innovative program uses a mobile laboratory to teach young students. This individual program receives a very large amount of funding totaling an estimated amount of $1,419,131 for three years. It started on June 1st, 2003 and ends on May 31, 2005. This program is part of the Division of Graduate Education. Another program offered by Boston University is "GK-12: A Blueprint for Integration of High School & Middle School Science and Mathematics: The Virtual Science Laboratory". This program has Boston University fellows improve the differences between middle school and high school mathematics and science courses, when looking at grades. The fellows' main purpose is to teach teams of students to use virtual models and other types of software along with hands on data collection in order to enhance scientific standards.

This program began on June 1, 2002 and will be running at Boston University until May 31, 2005. This program has been given an estimated budget of $1,377,106.00.

Another program that is similar to the one going on at BU is offered at Harvard University. (National Science Foundation, Funded Programs) [10] Harvard's program entitled GK-12 Environment, Materials Science, and Information Technology Themes in Eighth, Ninth and Tenth Grades is similar, yet different, in terms of grades it applies to. Harvard created a curriculum that is used to prepare Harvard and Cambridge Public schools to take the MCAS tests. The program offers curriculums in the environment, material science, and information technology. This program is planning on expanding into the eighth and ninth grades in the following years. Harvard University's program was initiated on April 1, 2001 and is scheduled to come to a close on March 31, 2005.

This program received an estimated \$1,171,500.00, which makes it also one of the most funded programs in Massachusetts.

Another program that also has a large amount of money allocated to it is the University of Massachusetts Amherst. The title of the program being done at University of Massachusetts Amherst is “GK-12: Science, Technology, Engineering and Mathematics UMass K-12 Connections (STEM Connections)”. This program is given an estimated amount of money which should total \$1,380,000.00. UMass Amherst’s program is described as a project that will provide knowledge to teachers on how to teach science in a project team based method. This program is more directed towards helping teachers learn the correct way to teach science and math, than it is on teaching students directly. This program started on June 1st, 2002 and is estimated to end around May 31, 2005. Its investigators are the Julian Tyson, Department of Chemistry as well as Morton Sternheim, and finally Kathleen Davis.

Another Massachusetts school that has programs associated with the NFS is Tufts University. “Tufts Engineering the Next Steps (TENS) GK-12 project” is the program offered by Tufts University. With a budget of an estimated amount of \$1,499,795.00, it is the highest NFS funded program in Massachusetts. Tufts’s program is described as a partnership with four schools from the Massachusetts area of Malden to teach engineering. TENS tries to focus on teaching teachers the correct way to teach students engineering and algorithm design. This is in an effort to have students increase their skills in engineering. This project program is also designed to produce interest in new fellows to take up this program. This individual program began on June 1, 2003 and ends like the rest of the NFS programs tentatively on May 31, 2005.

Another large budget program from the NSF is University of Massachusetts Boston. (National Science Foundation, Funded Programs) [10] The title of the program offered by University of Massachusetts Boston is “Watershed-Integrated Sciences Partnership (WISP) between UMass Boston and Local School Districts”. UMass’s project program offers seven public schools a unifying theme to teach science. The program also is being used to hone mathematics skills as well as reinforcing the original mathematics curriculum and also creating a bridge between mathematic ideas and science. This program is highly oriented in having fellows spend a large amount of time with teachers in and outside of the classroom. Both fellows and teachers spend time teaching their students and going to workshops to promote team collaboration and cooperation. UMass started its program on January 1, 2003 and is also scheduled to end around May 31, 2005. The investigators for this program are Robert Chen ECOS, Michael Shiaris, William Robinson, Marilyn Decker, and Hannah Sevian.

The final program offered by NSF in Massachusetts is at Northeastern University. With a budget of an estimated amount of $1,028,000.00, the program “GK-12: STEM (Science, Technology, Engineering, and Mathematics) Graduate Teaching Fellows Program” is well funded and well built. This program was started at Northeastern University and has been a strong, outstanding example of an NSF program. With such sponsors and partnerships from Hewlett Packard Foundation, Boston Public Schools, Museum of Science of Boston, and the New England Aquarium, this program will be able to train its fellows and teachers the correct way to teach their students. They are expected to teach mathematics, engineering, and technology and increase their students’ excellence in these fields. This program believes that to make excellent students you need to make excellent teachers. One thing that makes this program different from the others is that it takes into account the needs of a diverse student population and uses the information to build a stronger curriculum. The fellows make a connection between the public schools and the university. This program was one of the few that started fairly early; it began on September 1st, 1999 and was expected to expire on August 31, 2004 and has not yet. The investigators for this project program are David Blackman, College of Arts & Science/Sch. of Edu., Thomas Gilbert, and Bryant York. These schools all had large sums of money and the support of the NSF to help build strong programs to support younger students.

A program that is similar to the ones in Massachusetts is located at the University of Oklahoma Norman Campus. (National Science Foundation, Funded Programs) [10] The University of Oklahoma has created a program that has changed the way younger students learn and implement the ideas of mathematics and engineering. The program has been entitled "GK-12 Formal Proposal: Science and Technology Enhance Authentic Learning in The High Schools - Project STEALTH". Project "STEALTH" has thirteen graduates and twelve advanced undergraduates along with twelve secondary science and mathematics teachers working to create inquiry-based activities for secondary science and mathematics students. The fellows and teachers are planning on using laboratory exercises, group and individual projects, and actual field work to build experience. All of their projects for students are built to suit the course curriculum and focus on environmental science and engineering, new materials and their use, and civil infrastructures. STEALTH started early for an NSF program, it began on March 1st, 2001 and is estimated to run its course by February 28, 2005. The investigators of the program are Mark Nanny of the Dept. Civil Eng. & Environmental Science, Teri Rhoads, and Mary John O'Hair. These investigators have an estimated budget for their program of $1,490,010.00.

Another school that has an NSF program and is out of state but is still in the New England area is University of Maine. Having one of the most interesting program names, “GK-12: Sensors!”, the University of Maine, Orono sets itself apart in its approach to teaching younger students. The instructors John Vetelino of the Electrical and Computer Engineering Department, Stephen Godsoe, and Constance Holden describe their program as:

> “ The University of Maine (UMaine) College of Engineering proposes to partner with Bangor High School (BHS) to develop a model university/K-12 partnership based on the disciplinary theme of sensors. The proposed model integrates education and research for the benefit of BHS students and teachers, and graduate and advanced undergraduate students, and faculty, within the College of Engineering at UMaine. GK-12 Sensors! will involve faculty and students from the chemical, biological, electrical, computer, mechanical, civil/environmental, and spatial information engineering programs at the University of Maine. Five advanced undergraduate and ten graduate students will serve as GK-12 Sensor Fellows. Faculty members recognized for their teaching and research expertise in sensor-related areas will represent each of the major Engineering programs at UMaine. High school teachers and students will benefit from the integration of cutting-edge, standards-based STEM content within a variety of classes and extramural activities such as students competitions. Undergraduate and graduate students, and faculty will gain an understanding of the challenges and opportunities of K-12 education, while improving their communication and teaching skills. Industry involvement is also a key component of the proposed program. A variety of technologies, including ATM, as well as traditional media and presentations will disseminate "best practices" from GK-12: Sensors! across Maine and the nation. This project is receiving partial support from the Engineering Directorate. ”
> (National Science Foundation, Funded Programs) [10]

UMaine Orono started its program on May 1, 2002 and is ending around May 30, 2005. With a budget estimated around $1,374,861.00, UMaine has a chance to really initiate strong learning practices in Bangor High School.

The final out of state program that is similar to the ones located in Massachusetts is being run out of Syracuse University. The “GK-12: The Syracuse University/Onondaga County Schools Partnership for Improvement of Science Education Proposal” program from Syracuse follows the same ideals and principles found in the other NFS programs. This university run program has fellows teach basic STEM concepts in biology, chemistry, earth science, physics, and technology. With funding of around $1,486,402 this program uses technology like very few programs that are sponsored by the NSF. This type of program is similar to the other programs available in Massachusetts and in other states located across the United States. All the programs reviewed are part of the National Science Foundations strongest echelon of programs running in this country. The research being done at these schools will help build better programs to be implemented in schools in the future.

After reviewing each program we noticed that each school offered very similar strengths that could help the PIEE program. Each program implemented new ideas in getting students to use hand on activities to learn about engineering and science. They also had strong categories that helped give ideas to the building of lesson plans. All programs dealt with similar age groups and covered many of the topics that are being built in the PIEE program. After looking at all the programs we will be able to use the ideas offered by other schools to improve the PIEE program.

II
H
After School Program

This fall and spring Midland Street School ran an after school program for forty of their fourth grade students. These forty students are broken up into four sections of ten each. Two of the sections participate in the fall and two participate in the winter. The fall session runs from October 5th to December 1st, and the winter session runs from January 5th to March 2nd (Judy Miller, 2004) [8].

The material for the lesson plans is a PBS/WGBH™ series called Building Big. Building Big is a program made by PBS about large structures (PBS, 2000-2001)[13]. The after school program will be using the six meeting plan. The six meeting plan has the students learn about foundations, bridges, domes, skyscrapers, dams, and tunnels. After finishing a brief introduction, the students then build structures based on what they have learned. Week one, students construct a newspaper tower and discuss forces and loads. Week two, they construct a paper bridge and discuss tension, bending, trusses, and compression. Week three, they construct a geodesic dome. Week four, they talk about columns and attempt to build a column that will support their weight. Week five, they learn about pressure and how it relates to dams. Week six, they do an exercise called meeting in the middle, which teaches them how tunnel teams that dig from different sides connect in the middle. They then construct a tunnel using toilet paper rolls (PBS, 2000-2001) [13]. These lessons are meant to be an addition to what the students learn in school.

The Midland Street School portion of the fourth grade IQP team provided assistance to teachers during the fall and winter sessions.

II
I
GEMS/GEMS Jr.

GEMS [Girls in Engineering, Math and Science] was founded in 2001 by Stephanie Blaisdell, PhD, who is the director of the Diversity and Women's Programs at WPI. The idea of this program came from similar programs at Arizona State University, where Blaisdell received her doctorate. GEMS started with young women in grades ten through twelve as a residential program for only three days during the summer. In 2002, GEMS Jr. was created for girls in grades eight and nine. The staff of the program consists of WPI faculty, current WPI students, and WPI graduates. In order to participate in the program, the girls must apply with an essay and are selected by a thorough review process. (S. Sontgerath (SONT), 2004) [15]

This program was designed to give young women the opportunity to learn about possible careers in the field of engineering and technology. This program was also designed to encourage young women to look into a future with Massachusetts Academy and WPI. Massachusetts Academy is a high school that WPI affiliates itself with by offering college courses to the students on the WPI campus. (SONT, 2004) [15] In addition to learning about technology, there are many other activities such as bowling and karaoke. (Girls in Engineering, Math and Science, 2004) At the end of the program, there are evaluations of the activities and the attitudes of the girls before and after the program to show how they felt about engineering. (SONT, 2004) [15]

GEMS and GEMS Jr. connects with the PIEE Program by the effort and drive to show children and young adults the essential background of engineering and how math and science can be used as tools to solve real world problems. Whether the students are minorities, girls and young women, or Worcester elementary students, the goal of introducing them to engineering at a young age is the same in all of these programs organized by WPI and sponsored by the National Science Foundation.

II
J
Camp Reach

In a male-dominated society, it is difficult for women to become interested in 'typically male' subject areas such as science, technology, and engineering. At WPI, the Camp Reach program attempts to increase young girls' interest in these subject areas, their motivation towards education, and their self-confidence. (Blaisdell, S (SB), 2004) [21]

Background:

In a recent report, it is predicted that by 2028 there will be 19 million more jobs than workers who are trained to fill them. Also, it is estimated that women compromise only 9.1% of engineers in the US labor work force. With these startling statistics, it is easy to see that more interest needs to be created in the fields of engineering, science, and technology. Although effort has been made at the pre-college/college level to increase interest, this has produced marginal results with an increase of 4% from 1987-1997. Many studies have concluded that the most impressionable age is much earlier than college, and that the middle school years are the optimum range for increasing interest in math and science. In order to solve this problem, Professors of Engineering Chrys Demetry and Denise Nicoletti began Camp Reach; an outreach program at WPI that uses state-of-the-art facilities, a mentoring program, and projects that are aimed at helping society. (Camp Reach, 2003) [2]

The Program:

The main goals of the program are to increase awareness of science and math. In order to achieve this, projects are done in teams, using the engineering design process, and to teach aspects of a career in engineering. To reach these goals, projects and hands-on learning are utilized. The project consists of working in a team, using the engineering design process, and solving a problem for an organization in the Worcester community. The hands-on learning is referred to as 'Discovery Workshops' "which emphasize hands-on learning and exploration rather than finding a 'correct answer." The girls also attend key-note speakers and field trips to learn more about science and engineering. (CR,2003)[2]

In order to participate in the program, girls must submit an application. From this pool of girls, there is a judging of interest level and an essay. Then, participants are selected at random as to create a diversity of students who attend the program. Tables II.J.1 and II.J.2 show geographic and ethnic distributions. (CR,2003)[2]

Table 14: Geographic Distribution of Campers

	2001	*2002*	*2003*
Worcester	7	10	13
Wachusett Regional School District	4	6	5
Shrewsbury	4	3	1
Fitchburg/Leominster	3	1	1
Other Worcester County towns	8	10	9
Outside Worcester County	2	0	1
Did not specify	2	0	0

Table 15: Ethnicity Profile of Campers for Past Three Years

	2001		*2002*		*2003*	
	Number	Percent	Number	Percent	Number	Percent
African-American	2	7%	1	3%	1	3%
Caucasian	19	63%	23	77%	22	73%
Hispanic	2	7%	2	7%	2	7%
Asian	3	10%	2	7%		
Other specified			1	3%	2	7%
Did not specify	4	13%	1	3%	3	10%

The staff of the program include: alumni of the program, WPI staff, WPI faculty, WPI students, local elementary teachers, and professionals. (CR,2003)[2]

Projects:

In accordance with WPI's project based curriculum, Camp Reach uses a design project for a customer in the Worcester community. Some of the most remarkable projects were:

- Children's Garden: An area day-care center that needed help creating an efficient system for storing materials that was safe for babies and young children.
- AIDS Project Worcester: A local AIDS center that was redesigning its office space. The team along with a team of professionals gave their recommendations to the center.
- Girls Inc. swimming area: A children's camp that uses a pond in the summer for swimming. The pond had a problem with collecting debris from erosion and leaves, and every year it was cleaned by hand. The girls talked with experts and devised a permanent solution.

‘Discovery Workshops’:

- “Who Dun It”: An experiment involving forensic science were girls solve a ‘crime’ committed on the WPI campus involving jewelry.
- Sandcastles: With the help of a WPI Professor, the girls design sand castles to withstand the problems that face traditional sandcastles.
- “Round Round, I Get Around”: An experiment that helps girls to make accommodations for the physically handicapped.

(CR,2003)[2]

From this program, girls develop and reinforce any preexisting interest in science, engineering and technology. They also become more aware of their environments, and themselves. What began as an idea to increase women’s enrollment at universities across the country has blossomed into a 2-week program for young girls. (CR,2003)[2]

As stated in the previous section the goals of the PIEE Program, Camp Reach and GEMS Programs are similar. Reading about these two programs gave the IQP team a place to start the groundwork on this project.

II
K

Learning Styles by Age/Grade

Every child has a specific way of learning and understanding information that is presented to him/her. Learning is defined in Webster’s Dictionary as, "any permanent change in behavior that occurs as a result of a practice or an experience." (Webster’s Dictionary, 2004) [17] Teachers and doctors have noticed differences in learning styles between children in the age group ranging from age seven to age eleven. Between these important ages of student’s lives, they need to be immersed in as much information as possible. From the first stage of learning development, the style of learning is very in depth. (Tipton, Debbie (Tipton), 2002) [16]

A teacher by the name of Debbie Tipton described the developmental stage that fourth graders are going through, which she calls Concrete Operations Period. This period of time is when children are able to begin manipulating data mentally. Children are able to take the information at hand and begin to define, compare, and contrast it. Debbie Tipton explains this phase as:

> “If you were to ask a pre-operations child, "How does God hear prayer?" They would most likely answer that He has big ears. The concrete child would put a little more thought into it and answer something like this: "God is smart and he made some special earphones just so He could hear me." (Tipton, 2002) [16]

A concrete operational child is capable of logical thought that means the child still learns through their senses, but no longer relies on only them to teach him/her.

Children within the seven to ten year old group are very literal in their thinking, they will take everything said and taught at face value. Debbie Tipton says that these children have a difficult time with symbols and figurative language. This was only the first stage of Debbie Tipton's learning development stages.

The second step of this learning development system is the Formal Operations Period. This stage is when children turn eleven years old. During this time a child goes through a huge transition in thinking and learning. Children usually break through the barrier of literalism and start to think in more abstract terms. Thinking is no longer restricted to time and space, which allows them to reflect, hypothesize, and theorize. One thought given is to stimulate the cognitive abilities of these children, where the cognitive skills can be broken down into seven categories. The seven cognitive skills that are believed to help in the learning abilities of children are knowledge of facts and principles, comprehension, application, analysis, synthesis, and evaluation. Debbie Tipton also explains what she believes are the best methods for teaching children:

> "1. A child rarely learns in isolation.
> 2. Learning most generally takes place in a setting of children within the same age group.
> 3. Some factors that affect learning are motivation, peer relationships within the group, and communication between the child and the teacher.
> 4. Other factors are environment, physical setting, emotional atmosphere, and social and cultural norms." (Tipton, 2002) [16]

These key points in learning are only one person's ideas on the correct way to teach the age group found in the fourth grade. There are other ideas that base themselves on theories of different learning groups, that people are categorized into specific types of people and ways they absorb knowledge.

Learning styles can be broken down into three main categories, which encompass all aspects of learning. The first style of learner is a visual learner. This type of person does very well with anything that they can see written on paper or physically. Spelling and math often come easily for visual learners since they can physically see the word or problem. They are characteristically neat and care about how things look. They learn more by watching and can call up images from the past when trying to remember. They use visual imaging to picture the way things will look or how things need to be done. These types of learners enjoy movies, pictures, museums, charts, maps, and graphs. The best way to teach them is to make mental pictures in their heads and use visual words to describe shape, form, color or size. (Tipton, 2002) [16]

The next type of learner is an auditory learner, or someone that can understand things verbally. These type of learners can understand information better when it is told to them rather than in a visual manner. They often spell words the way they sound rather than how they see it in print. They have trouble with reading because they do not visualize well. Some auditory learners have conversations aloud with themselves or others because they understand written words only when they hear them. They like to talk things over, and they do well when people contribute verbally in small or large groups in such things like plays or debates. Learners like this enjoy imagining how things will sound and remember facts best when they are presented in forms like poems or songs. (Tipton, 2002) [16]

The final type of learner is a kinesthetic learner, they learn through doing it themselves. Parent Pipeline described this type of learning as:

> "Kinesthetic learners learn by doing. They learn best through movement and manipulation. They like to find out how things work and are very successful in the practical arts. When given a choice of assignments, such as writing a book report or making a scene from a book, they will make the scene. They can learn to read and follow directions through the use of recipes, etc. Most kinesthetic learners move around a

> lot (rock in chair, tap feet) and have trouble sitting for long periods. They like to dance, participate in sports and use their hands. They may even like the feel of fabric rather than the look of the clothes they wear. This explains why they like to study on a carpet or textured bedspread. Although it might appear distracting, they may have to walk around while doing their homework assignment. They are also very sensitive to feelings in themselves and others. (North Dakota State University, 2004) [12]

These learning styles are used to describe the techniques best used to teach different types of students and people. The basic view on students is that each one learns differently and has to change their ways of learning to better understand all the information provided.

The general consensus of professionals in the field of elementary education is that the learning styles of fourth grade students are very difficult to truly understand. Children of this age group learn very differently. They handle classes and everything that comes with school very differently which in a large part depends on the demographics of their school and surrounding area. Students in a city learn differently from students located in rural areas; this makes classifying children into any type of learning category very difficult.

III
Project Objectives

In the original proposal to the National Science Foundation, this project was founded to produce several outcomes. These outcomes include: Producing a model system of students, teachers, professors, and fellows to work in a team together toward a common goal, to implement the Massachusetts Science/Technology Engineering Curriculum Frameworks (MSTECF), and to assess the curriculum, the students, and how prepared the teachers are from the project.

From this project, the team has focused on two aspects of the NSF proposal. The main goals of the IQP project were **i)** to produce three lesson plans per IQP student, **ii)** to implement these lesson plans, and **iii)** to assist the teachers in the classroom while these lessons were implemented. The topics of these lessons covered all aspects of the Massachusetts Frameworks and Worcester Public School Benchmarks.

IV

In the section that follows is the collection of lesson plans that the IQP team produced during the 2004-2005 school year. The topics of the lessons were set by the IQP fellows, and then created by the IQP students according to the WPS Benchmarks. Each student created four lessons, and then helped teachers implement them in the classroom.

IV
A

Lesson Title: Ecosystem That Can Sustain a Tadpole

Grade Level: 4^{th}

Lesson time: One class to construct, observation of water cycle/life cycle, several days

Instructional Mode: Large group

Team/Group Size: 2 or 3 students

Summary: Students will design and build an ecosystem that will support a tadpole. The goal of this lesson is to teach students about the life cycle, water cycle, and how an environment is dependent upon others for survival.

Learning Objectives:

2004 Worcester Public Schools Benchmarks for the 4^{th} Grade

<u>Skills of Inquiry</u>

Students will...

04.SC.IS.01: Ask questions and make predictions that can be tested.

04.SC.IS.03: Keep accurate records while conducting simple investigations or experiments.

04.SC.IS.06: Record data and communicate findings to others using graphs, charts, maps, models, and oral and written reports.

<u>Earth/Space Science</u>

Students will…

04.SC.ES.08: Draw a diagram of the water cycle. Label evaporation, condensation, and precipitation. Explain what happens during each process.

<u>Life Science</u>

Students will…

04.SC.LS.01: Describe the major stages that characterize the life cycle of the frog and butterfly as they go through metamorphosis.

04.SC.LS.02: Using either live organisms or pictures/models, observe the changes in form during the life cycle of a butterfly or frog.

04.SC.LS.06: Compare and contrast the physical characteristics of plants or animals from widely different environments (desert vs. tropical plants; aquatic vs. terrestrial animals). Explore how each is adapted to its habitat.

<u>Technology/Engineering</u>

Students will…

04.SC.TE.01: Identify materials used to accomplish a design task based on a specific property (e.g., weight, strength, harness, and flexibility.)

04.SC.TE.05: Describe different ways in which a problem can be represented (e.g., Sketches, diagrams, graphic organizers, and lists.)
04.SC.TE.08: Apply the metric system in design projects and experiments.

Essential Questions:

How does the water cycle work?
Why is an ecosystem interdependent upon itself?
Why do frogs have tadpoles instead of producing smaller frogs?

Procedure:

1. Give each student the materials required to create the ecosystem. Ask them how they would construct an ecosystem using the given materials. Have them complete the steps of the engineering design process.
2. Construct the ecosystem:
    a. Cut top off one of the 2 liter bottles, cut bottom off the other.
    b. Fill the bottle missing the top with water. This needs to be de-chlorinated.
    c. Fill other bottle with small rocks, and then potting soil. (Have students choose their own amount of each item to put in the bottle so as a class they may obtain and analyze different results.)
    d. Place creatures/plants in the bottle with water.
    e. Tape the bottle missing a bottom onto the top of the other bottle.
    f. Using seeds, place them in the soil.
    g. Tape the cellophane onto the top of the bottles.
    h. OBSERVE!

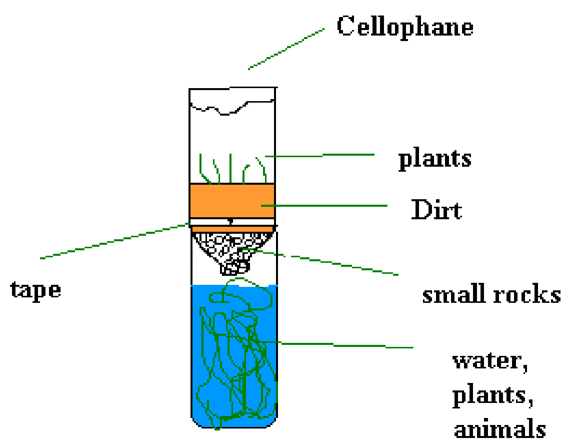


Figure 1: Ecosystem Model

Materials:

-2 Two-Liter Soda Bottles (per group)
-Cellophane (less than one standard roll)
-Plants (Grasses in seed form, alphalpha sprouts, etc.)
-Potting Soil (enough for each group to put their desired amount in their bottle)
-Small Rocks (enough for each group to put their desired amount in their bottle)
-Tape (one roll is sufficient)
-De-chlorinated water (slightly less than 2 liter per group)
-Tadpole (one per group)
-Plants for tadpoles to eat

Vocabulary with Definitions:

Ecosystem**-** a system formed by the interaction of a community of organisms with their physical environment

Metamorphosis- A change in the form and often habits of an animal during normal development after the embryonic stage. Metamorphosis includes, in insects, the transformation of a maggot into an adult fly and a caterpillar into a butterfly and, in amphibians, the changing of a tadpole into a frog.

Life cycle- The course of developmental changes through which an organism passes from its inception as a fertilized zygote to the mature state in which another zygote may be produced.

Water cycle- The cycle of evaporation and condensation that controls the distribution of the earth's water as it evaporates from bodies of water, condenses, precipitates, and returns to those bodies of water. Also called hydrologic cycle.

Assessment/Evaluation of Students:

Grade based on the individual effort of the student, their ability to work in a group and the presentation of the groups findings to the class.

Safety Issues:

Cut bottles for students, dangerous if done improperly.
Be sure there are no jagged cut edges that the students can cut themselves on.

Key Words: Ecosystem, Metamorphosis.

IV
B

Lesson Title: Periscope

Grade Level: 4th

Instructional Mode: Large Group

Team/ Group Size: 2-3

Summary: The objective is to design and build a periscope that a student can use to see around a corner. The students should understand how a mirror works, and discuss reflection. The students must first draft their ideas, and then build a working model. The students should have completed a working model by the end of the class period

Learning Objectives:

2004 Worcester Public Schools Benchmarks for 4th Grade

Skills of Inquiry

Students Will…

04.SC.IS.01	Ask questions and make predictions that can be tested.
04.SC.IS.02	Select and use appropriate tools and technology

Physical Science

Students Will…

04.SC.PS.02	Identify the basic forms of energy.

Technology/Engineering

Students Will…

04.SC.TE.01	Identify materials used to accomplish a design task based on specific property.
04.SC.TE.02	Identify and explain the appropriate materials and tools to construct a given prototype safely.
04.SC.TE.06	Identify relevant design features for building a prototype of a solution to a given problem.

Essential Questions:

How should you angle the mirrors?
What type of line does light move in (straight or curved)?
After light is reflected, does it still move in the same fashion?
Where should you cut viewing holes?

Introduction/Motivation:

Talk about a periscope on a submarine.
See Attached Documents

Procedure:

1. Ask Students what a mirror is for and how it works
2. Pass out attachment on mirror basics
3. Start engineering
4. Give students the two page worksheet on the Engineering Design Process
5. Have the students fill out all the steps up until it says build a prototype.
6. Building the prototype

    Using duct tape, tape two paper towel rolls together.
    Using duct tape, tape each end shut.
    Using scissors, cut two holes for light to exit and enter.
    Using duct tape, angle the mirrors and tape them to the top and bottom of the roll.
7. When the students are finished have them test their periscope by sitting on the floor and position the periscope so they can see over their desk.
8. Have the students fill out the rest of the worksheet, give heavy emphasis on the redesign portion.

    The periscope should look like this:

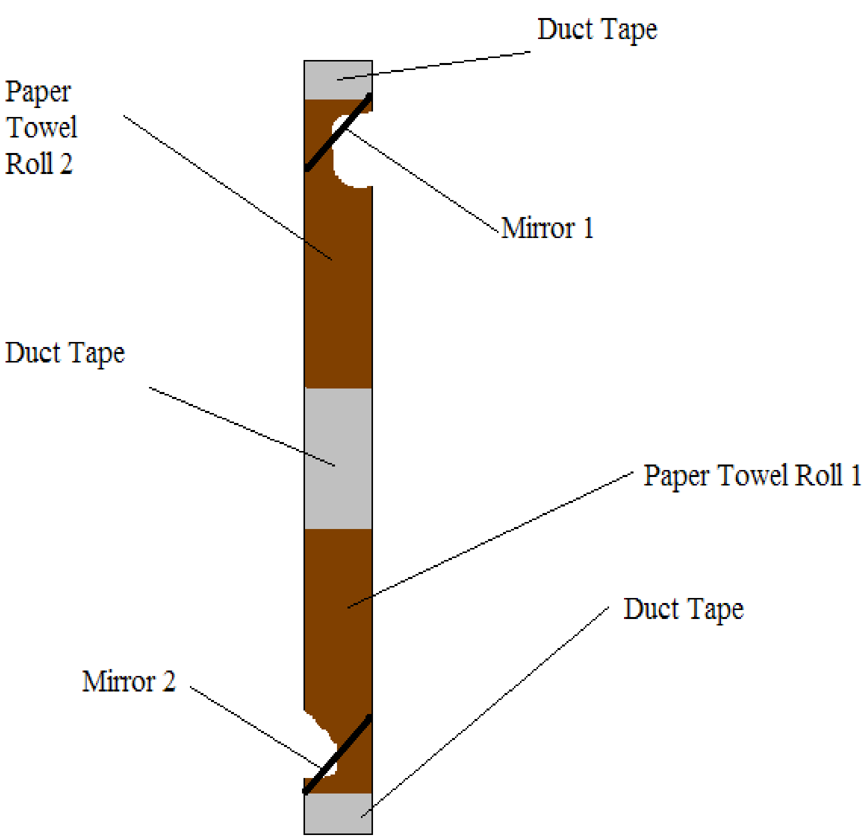


Figure 2: Periscope Model

Materials:

-Empty paper towel rolls (two per group)
-Duct Tape (one roll)
-Scissors (one pair per group)
-Pocket Mirrors (two per group, size dependant on size of paper towel rolls, can be purchased from a hardware store)

Vocabulary with Definitions:

Reflect- To throw or bend back (light, for example) from a surface.

Trajectory- The path of a projectile or other moving body through space.

Illuminate- To provide or brighten with light.

Assessment/Evaluation of Students:

Students are graded on their ability to meet the criteria of the problem, and on their ability to follow the engineering design process.

Attachments:

Protocol for the Periscope
Periscope Picture
Periscopes and Submarines
How a periscope works

Safety Issues:

Be careful with the scissors, and give a quick talk about how to handle them properly.

How a mirror works

The reason we see is because light illuminates our world. Our eyes see light that is reflected off of objects, and our brain translates what the eye sees into an image. A mirror reflects incoming light by changing the trajectory of the light.

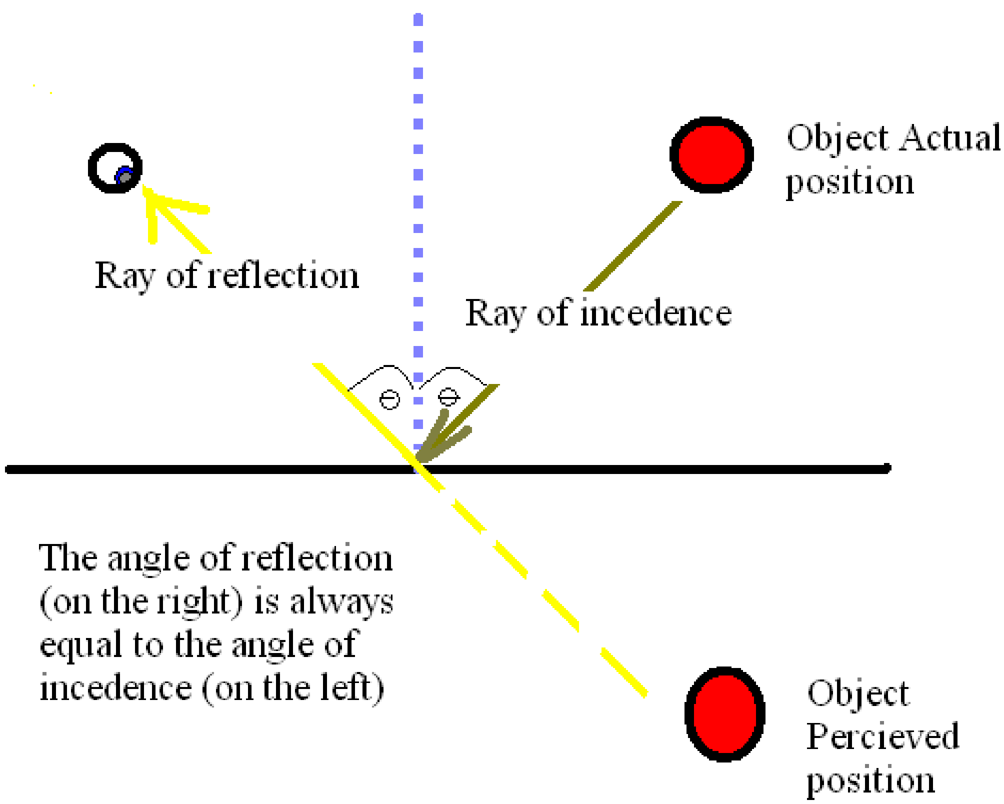


Figure 3: How a Mirror Works

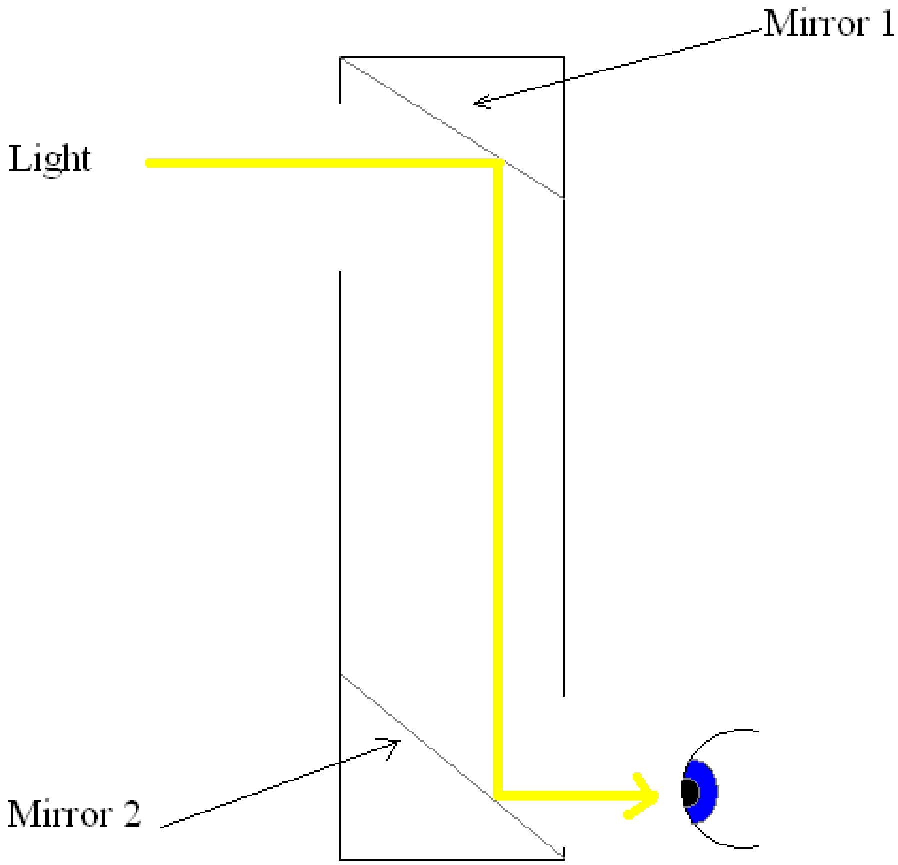


Figure 4: How light travels through a Periscope

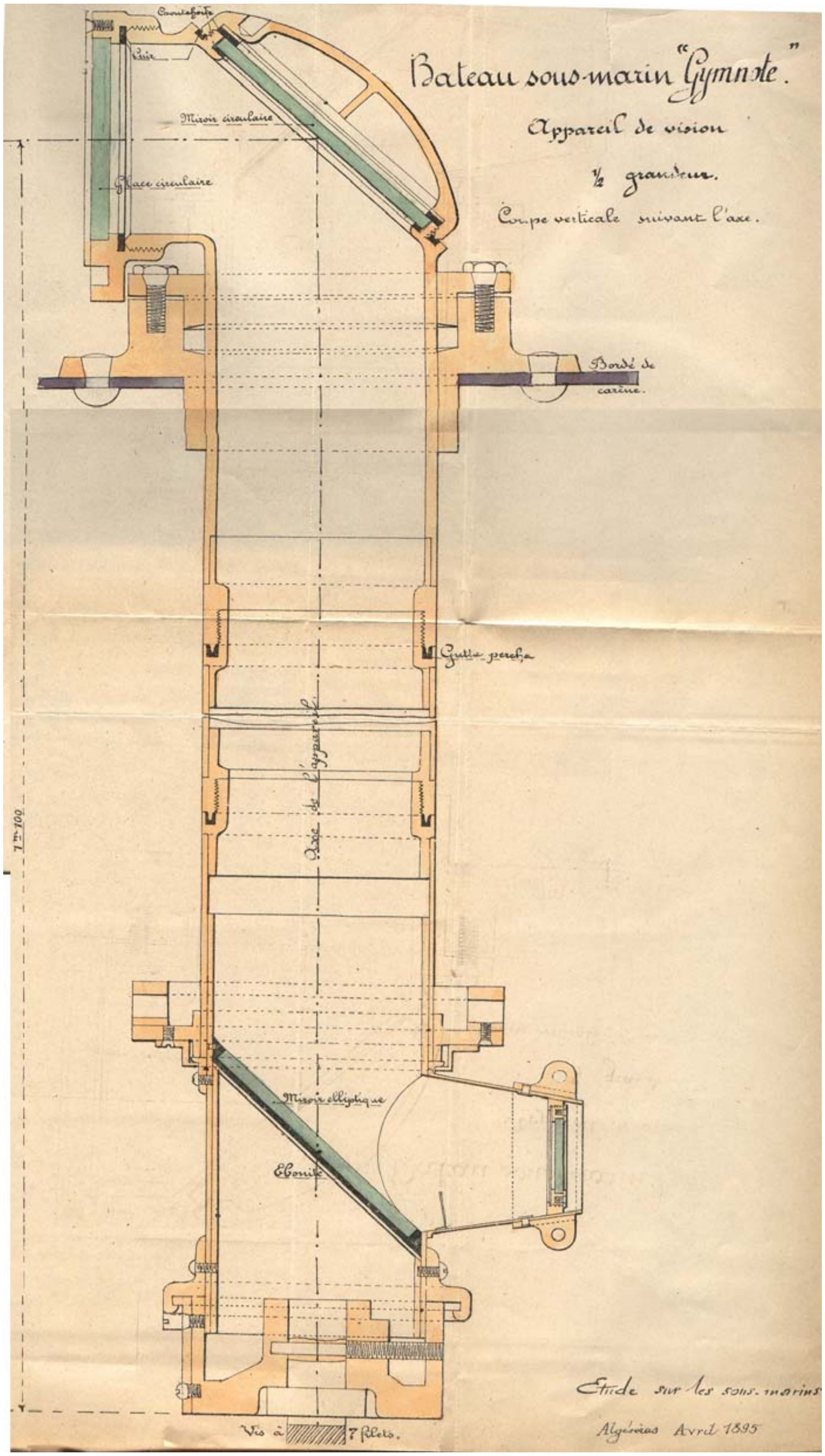


Figure 5: Periscope Schematic

http://rrrbmn05.waika9.com/Gymnote_Periscope_0-1_1889.jpg

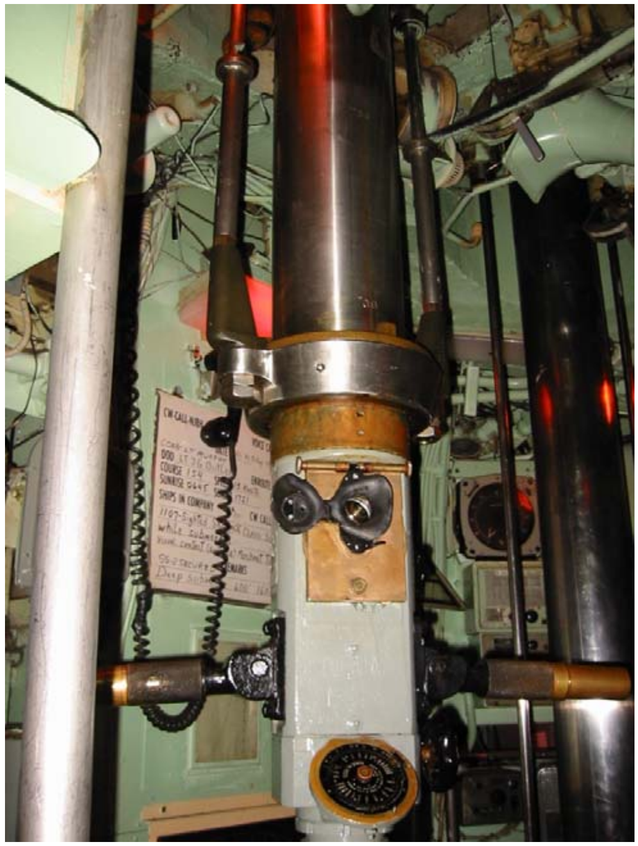


Figure 6: Submarine Periscope

http://www.pics.kaybee.org:81/Vacations/NewYork2002/USSIntrepid/periscope.jpg

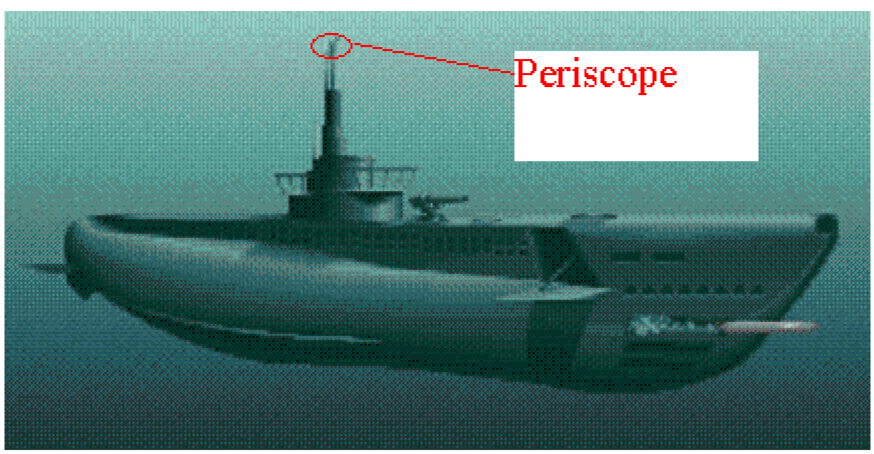


Figure 7: Periscope Location on a Submarine

http://pearl1.lanl.gov/periodic/%20images/submarine.gif

IV
C

Lesson Title: Rubber Band Banjo

Grade Level: 4th

Lesson Time: 50 minutes

Instructional Mode: Entire Class

Summary: The students will learn how to make a basic musical instrument and how to modify it to get different loudness and pitches.

Learning Objectives:

2004 Worcester Public Schools Benchmarks for the 4th Grade

<u>Physical science</u>

Students will...

04.SC.PS.01: Design and construct a simple sound-producing device to predict, demonstrate, and describe the properties of loudness and pitch of sound.

<u>MSTECF Standards</u>

4.3.11: Recognize that sound is produced by vibrating objects

Essential Questions:

How can I modify the loudness and pitch of my rubber band banjo?

Procedure:

1. Review sound and pitch quickly (10 minutes)
2. Split the class into groups of two students: (40 minutes)
    a. Hand out materials to each group
    b. Write the numbers 1-8 on the inside of the lid. Use a ruler to space them evenly across the whole lid. (See attachment: Banjo)
    c. Put four thick rubber bands around the lid over the numbers 1 through 4.
    d. Put four thin rubber bands around the other half of the lid over the numbers 5 through 8.
    e. Have the students answer the following questions in their science notebook:
        i. Pluck one of the rubber bands. How can you make a soft sound? Louder sound?
        ii. Which bands (thick or thin) make higher sounds? (the highness and lowness of a sound is pitch)

iii. Press down a rubber band halfway across the lid. Pluck the piece of the rubber band closest to you. What happens to the pitch when you shorten the rubber band?
iv. How does tightening the band have an affect on pitch? Loosening the band? (you can do this by pulling the band near the edge of the cover.
v. Try to make an 8-note scale. (Do-Re-Mi-Fa-So-La-Ti-Do) (pluck lightly so the strings stay tuned)
vi. Once tuned, have them play 1-1-1-2-3 3-2-3-4-5 8-8-8 5-5-5 3-3-3 1-1-1 5-4-3-2-1. See if they can figure out what song it is. (Row-Row-Row your boat)

Materials List (per group):

-Shoe box lid (or the equivalent)
-4 thick rubber bands
-4 thin rubber bands

Vocabulary with Definition:

Frequency– How fast something (like a sound producing rubber band) vibrates. The faster the vibration, the higher the frequency.

8-note Scale– The basic notes of Do-Re-Mi-Fa-So-La-Ti-Do

**All other vocabulary and definitions should have been thoroughly covered in the last two lessons.*

Assessment/Evaluation of Students:

Grade based on the student's effort, the student's grasp of the concepts or frequency and pitch and group-work ability.

Attachments: Stringed Instruments, Rubber Band Banjo Background, Banjo

Key Words: Sound, Pitch, Loudness, 8-note scale

Sources: Science in Elementary Education 7th Edition, Peter C. Gega, 1994

Rubber Band Banjo Background

Preparation and Background:

The tightness, thickness, and length of a rubber band (or string) all affect its pitch. Sounds are higher with taut, thin, short strings; they are lower with looser, thicker, or longer strings on any stringed instrument. The tension of each rubber band may be adjusted by pulling up or down at the side of the lid. Friction between the band and the lid hold the band in place for a while. However, the band will need to be strummed or plucked gently. A sturdy lid is preferable to a flimsy one that bows in the middle.

Generalization:

The length, tension and thickness all affect the pitch of the vibrating string/rubber band.

Comments:

Parts 5 and 6 can be somewhat difficult and not all students may be able to understand/complete them. These are more like extra credit problems for groups that excel in sound and waves.

Sources –

Science in Elementary Education 7th Edition, Peter C. Gega, 1994

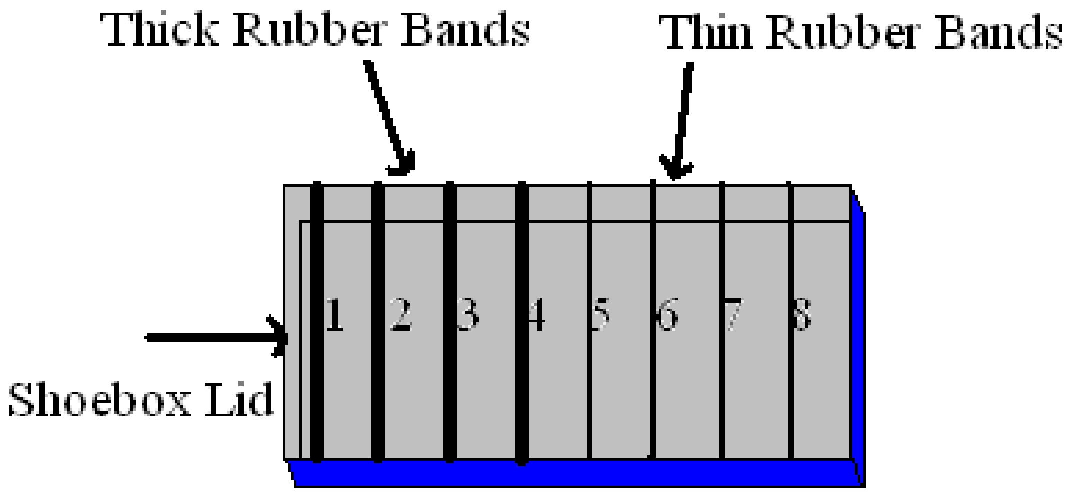


Figure 8: Example of a Rubber Band Banjo

Sources –

Science in Elementary Education 7th Edition, Peter C. Gega, 1994

Stringed Instruments

***Teacher's note*:**

Please do not teach this word for word. Read and understand it yourself and only teach what you feel is necessary to get the lesson and vocabulary across to your students.

In a stringed instrument, pitch depends on the length, tightness, and thickness of the strings. Shortening a string causes faster vibrations, raising pitch. Lengthening it has an opposite effect. Tightening a string also increases pitch, whereas lessening tension decreases it. A thick string vibrates more slowly than a thin one, and so produces a lower sound.

Why do different instruments- a violin and a cello, for instance- play a note at the same pitch yet sound different? This is because of the *quality* of tone (timbre) produced by these instruments. Most vibrations include more than just simple, back-and-forth movements along a strings entire length. Although there is a fundamental vibration that covers the basic pitch, other strings vibrate at faster frequencies. The combinations of vibrations are different with each string and with various stringed instruments. Together they produce tones of distinctly recognizable quality.

Sources –

Science in Elementary Education 7th Edition, Peter C. Gega, 1994

IV
D

Lesson Title: Greenhouse

Grade Level: 4^{th}

Instructional Mode: Large Group

Team/ Group Size: 2

Summary: The objective is to get the students to understand how greenhouses work and what the greenhouse effect is. The students should be able to understand the cycle of a bean growing from a seed to a full plant. They will have to guess at what color light will cause the plants to grow faster. Also, there will be limited supplies and a timeframe for the entire project. The groups will put each plant into a small greenhouse and under a heat lamp with a different color. At the end of the project the groups will present their findings to the class.

Learning Objectives:

2004 Worcester Public Schools Benchmarks for 4^{th} Grade

Skills of Inquiry

Students will…

04.SC.IS.01	Ask questions and make predictions that can be tested.
04.SC.IS.02	Select and use appropriate tools and technology (e.g., calculators, computers, balances, scales, meter sticks, graduated cylinders) in order to extend observations.
04.SC.IS.03	Keep accurate records while conducting simple investigations or experiments.
04.SC.IS.05	Recognize simple patterns in data and use data to create a reasonable explanation for the results of an investigation or experiment.
04.SC.IS.06	Record data and communicate findings to others using graphs, charts, maps, models, and oral and written reports.

Life Science

Students will…

04.SC.LS.03	Differentiate between observed characteristics of plants and animals that are fully inherited (e.g., color of flower, shape of leaves, color of eyes, number of appendages) and characteristics that are affected by climate or environment (e.g., browning of leaves due to too much sun, biorhythms).
04.SC.LS.07	Give examples of how changes in the environment (drought, cold) have caused some plants and animals to die or move to new locations (migration).

04.SC.LS.08 Investigate how invasive species out-compete native plants (e.g., phragmites and purple loose-strife). Discuss how some native plants die as a result.

Technology & Engineering

Students will…

04.SC.TE.01 Identify materials used to accomplish a design task based on specific properties

04.SC.TE.04 Identify a problem that reflects the need for shelter, storage or convenience.

04.SC.TE.05 Describe the different ways in which a problem can be represented (e.g., sketches, diagrams, graphic organizers and lists).

04.SC.TE.06 Identify relevant design features (e.g., size, shape, weight) for building a prototype of a solution to a given problem.

Essential Questions:

How does a greenhouse work?
What is "the greenhouse effect"?
How does a bean grow?
What color light causes plants to grow faster?

Procedure:

1. Using paper or plastic cups, students will plant one bean in soil.
2. Each group of two will build a greenhouse out of the bottom half of a 2 liter bottle.
3. The groups will water their plants once a day,
4. The plants will be kept under one of three colored lights. The three color lights will be yellow, green, and blue.
5. Students will measure the size of the plants as they grow and record it in their notebooks.
6. At the end of three weeks the students will give their findings in front of the class.

Materials:

Lima beans (one per group)
plastic cups (one per group)
2 liter bottles (one per group)
heat lamps (available at hardware store)
colored light bulbs (available at hardware store)
watering can

Vocabulary with Definitions:

Greenhouse- A structure, primarily of glass, in which temperature and humidity can be controlled for the cultivation or protection of plants.

Greenhouse effect- warming that results when solar radiation is trapped by the atmosphere; caused by atmospheric gases that allow sunshine to pass through but absorb heat that is radiated back from the warmed surface of the earth

Heat- A form of energy associated with the motion of atoms or molecules and capable of being transmitted through solid and fluid media by conduction, through fluid media by convection, and through empty space by radiation.

Moisture- Diffuse wetness that can be felt as vapor in the atmosphere or condensed liquid on the surfaces of objects; dampness.

Assessment/Evaluation of Students: Graded on drafts, participation and presentation.

Troubleshooting Tips:

Make sure the students do not over water their beans.
The beans will grow fast; everyone must pay attention to how fast the plants grow.

Safety Issues:

The heat lamps will get hot. <u>Do not touch the bulbs</u>.

IV
E

Lesson Title: Flashlight

Grade Level: 4th

Instructional Mode: Large Group

Team/ Group Size: 2

Summary: The objective is to get the students to understand how to build a circuit. The students should understand a simple circuit, light, and reflection. They will have to use a drafting form before starting the building process. Also, there will be limited supplies and a timeframe for the entire project. The flashlight should be able to work and be presented to the class on completion.

Learning Objectives:

2004 Worcester Public Schools Benchmarks for 4th Grade

Skills of Inquiry

Students Will…

04.SC.IS.01	Ask questions and make predictions that can be tested.
04.SC.IS.02	Select and use appropriate tools and technology
04.SC.IS.03	Keep accurate records while conducting simple investigations or experiments.
04.SC.IS.04	Conduct multiple patterns in data to test a prediction. Compare the results of an investigation or experiment with prediction.
04.SC.IS.06	Record data and communicate findings with others using graphs, charts, maps, models, and oral and written papers

Physical Science

Students Will…

04.SC.PS.02	Identify the basic forms of energy.
04.SC.PS.05	Recognize that electricity in circuits requires a complete loop through which an electrical current can pass, and that electricity can produce light, heat and sound.
04.SC.PS.06	Identify and classify objects and materials that conduct electricity and objects and materials that are insulators of electricity.
04.SC.PS.07	Determine the electrical conductivity of a collection of materials by testing the materials with a simple battery/ bulb circuit.

Technology/Engineering

Students Will…

04.SC.TE.01	Identify materials used to accomplish a design task based on specific property.
04.SC.TE.02	Identify and explain the appropriate materials and tools to construct a given prototype safely.
04.SC.TE.06	Identify relevant design features for building a prototype of a solution to a given problem.

Essential Questions:

What is a simple circuit?
How does a simple circuit work?

Introduction/Motivation:

Show the students a previously built flashlight that followed the protocol.

Procedure:

1. Using scissors cut a small square about the dimensions of a 9V battery in the middle of the paper towel roll.
2. With the piece of cardboard, tape it secure inside of the paper towel roll so that it is parallel with the hole that was cut (makes sure that it is opposite of the hole so that it is not covered) and be sure to leave about 3" of the cardboard piece out one side.
3. Make a funnel with the aluminum foil so that the light bulb can have something to reflect off.
4. Wrap the aluminum foil funnel around the light bulb and tape it secure. Make sure that the prongs of the light bulb are exposed.
5. Tape the light to the cardboard flap that is sticking out of the roll. The light bulb should be facing out.
6. Snake the two wires starting from the hole on top to the bulb.
7. Connect the wires to the bulb in the appropriate designation of current.
8. Tape the wire secure to the cardboard flap
9. Place the battery in the hole on top and tape it secure.
10. Connect the wires to the proper designation of current on the battery.

The flashlight should look like this:

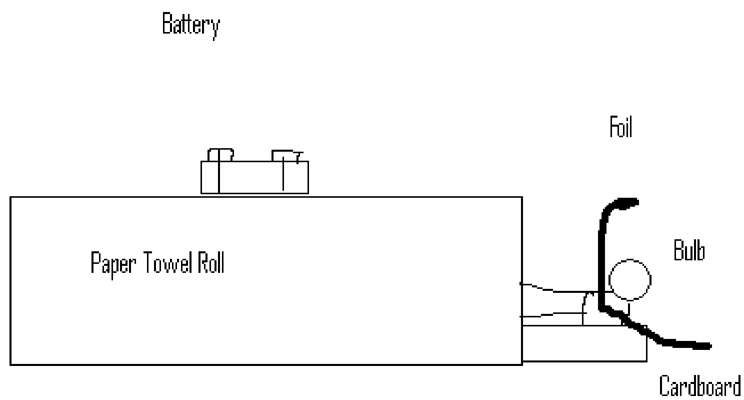


Figure 9: Flashlight Schematic

Materials (per group):

-1 Empty paper towel roll (or toilet paper roll)
-Light bulb (preferably small, can find them in a simple circuit kit)
-Circuit kit with a battery holder or use regular small single current wire if kit is unavailable and attach it to the terminals on the battery and the end of the bulb at the designated terminals.
-1 AA Battery (9V would be the best if there is no harness with a kit)
-Tape (1 roll per class)
-1 Piece of cardboard (dimensions 1” X 4”)
-Aluminum foil (less than one standard roll)
-1 pair of scissors

Vocabulary with Definitions:

Circuit- A closed path that allows electrical current to run through it.

Electricity- The flow of electrons in a circuit.

Conductivity- The ability of a material to transfer electrical energy.

Assessment/Evaluation of Students: Graded on worksheets, participation and presentation.

Attachments: Drafting sheets and background worksheet.

Troubleshooting Tips:

If the light does not work, test the power of the battery or check the coils in the bulbs. Also, check to see if the wires have been properly secured to the battery.

Safety Issues:

Be sure the students handle the bulbs with care. A bulb can break and the shards can be harmful. Also, make sure the batteries are not leaking/secreting any fluid. The experiment should be preformed in a dry safe environment.

IT'S ELECTRIFYING!!!

Draw a basic picture of a simple circuit and label the direction of electrical flow (positive and negative).

Name three things in your house that uses simple circuits.

1.__________________________________

2.__________________________________

3.__________________________________

How might you engineer a way so that you can get 3 light bulbs to light at the same time when you only have one source of electricity? Feel free to draw a picture to explain your answer.

Figure 10: Built Flashlight

Figure 11: Built Flashlight from Side

IV
F

Lesson Title: Simple Forces 1, "Marble Madness"

Grade Level: 4th

Lesson time: One day for background, one day for game

Instructional Mode: Large group

Team/Group Size: 2 students

Summary: Students will play a game using marbles and a simple game board. The objective is to shoot a marble at another marble to get the second marble in a cup.

Learning Objectives:

2004 Worcester Public Schools Benchmarks for 4th Grade

Skills of Inquiry

Students will…

- 04.SC.IS.01: Ask questions and make predictions that can be tested.
- 04.SC.IS.03: Keep accurate records while conducting simple investigations or experiments.
- 04.SC.IS.04: Conduct multiple trials to test a prediction. Compare the results of an investigation or experiment with the prediction.
- 04.SC.IS.05: Recognize simple patterns in data and use data to create a reasonable explanation for the results of an investigation or experiment.
- 04.SC.IS.06: Record data and communicate findings to others using graphs, charts, maps, models, and oral and written reports.

Physical Science

Students will…

- 04.SC.PS.03: Give examples of how energy can be transferred from one form to another.

Technology/Engineering

Students will…

- 04.SC.TE.01: Identify materials used to accomplish a design task based on a specific property (e.g., weight, strength, harness, and flexibility.)
- 04.SC.TE.05: Describe different ways in which a problem can be represented (e.g., Sketches, diagrams, graphic organizers, and lists.)
- 04.SC.TE.08: Apply the metric system in design projects and experiments.

Essential Questions:

Why is a flat surface used instead of one with several holes?
Why are marbles used instead of small blocks?
What is the most effective way to shoot the marble into the cup?
Is there a direct path for the marble, or did you use other elements to shoot the marble into the cup?

Procedure:

1. Make the game boards beforehand.
2. Split class into relevant groups for the activity. Two students are recommended per group as this will provide adequate access for each student to ‘play the game.’

Vocabulary:

Friction- A force that resists the motion of an object when it is touching another object.

Gravity- The force that causes objects to fall to the ground

Inertia- The tendency for an object that is at rest to stay at rest and for an object that is moving to stay moving.

Energy- The capacity of a physical system to do work.

Assessment/Evaluation of students:

Ability to work as a group, participation, presentation of findings to class.

Attachments: Diagram of Game

Safety Issues: Game boards need to be constructed prior to lesson.

Redirect URL:

http://www.glenbrook.k12.il.us/gbssci/phys/Class/newtlaws/newtltoc.html

Key Words: Sir Isaac Newton, 3 Laws of Motion

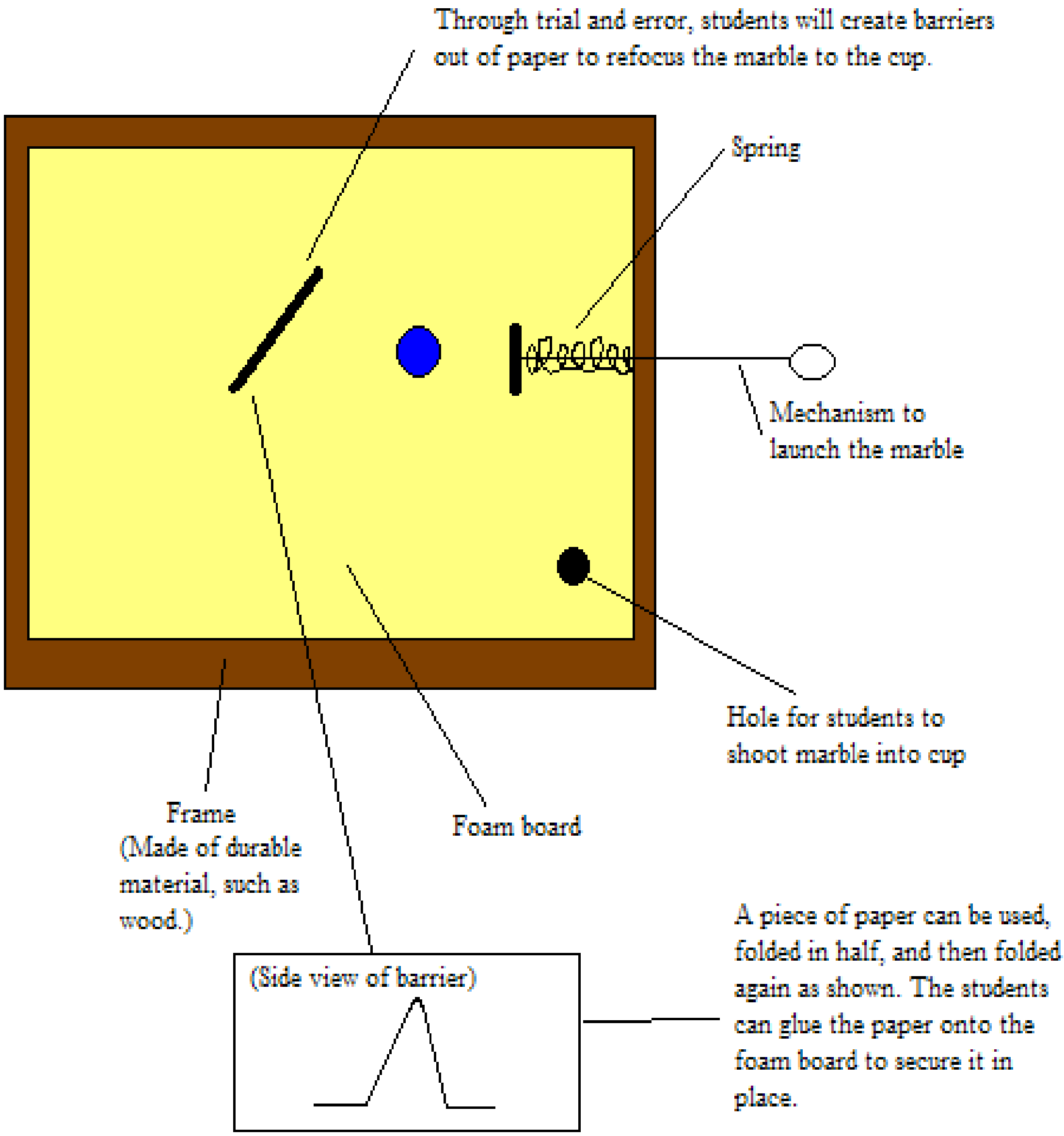


Figure 12: Marble Madness Game Board

IV
G

Lesson Title: Natural Water Filter

Grade Level: 4th

Instructional Mode: Large Group

Team/Group Size: 4 students

Summary: Students will design and construct a water filter using a 2 plastic 2 liter bottles and layers of natural material.

Learning Objectives:

2004 Worcester Public Schools Benchmarks for 4th Grade

Skills of Inquiry

Students Will…

04.SC.IS.01	Ask questions and make predictions that can be tested.
04.SC.IS.03	Keep accurate records while conducting simple investigations or experiments.
04.SC.IS.06	Record data and communicate findings with others using graphs, charts, maps, models, and oral and written reports.

Technology/Engineering

Students Will…

04.SC.TE.01	Identify materials used to accomplish a design task based on specific property.
04.SC.TE.02	Identify and explain the appropriate materials and tools to construct a given prototype safely.
04.SC.TE.06	Identify relevant design features for building a prototype of a solution to a given problem.

Essential Questions:

How does a natural water filter work?

Introduction/Motivation:

Introduce to the students a sieve or lettuce spinner. Show how it only lets object below a certain size to pass through it.

Procedure:

1. Pass out the Engineering Design Worksheets.
2. Have student sketch a model of the water filter.
3. Have student break into groups and start assembling the filter.
4. When a student finishes have them pour a dirty cup of water through the filter.

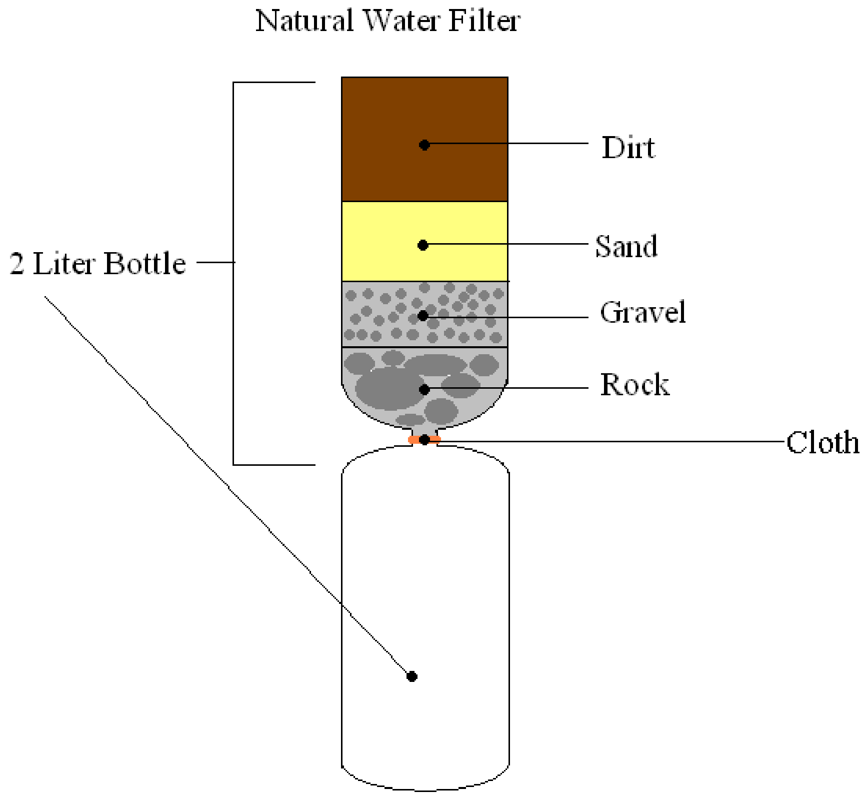


Figure 13: Natural Water Filter Schematic

Materials:

-2 liter soda bottles (2 per group)
-Dirt*
-Sand*
-Rocks*
-Gravel*

*enough of these materials should be provided so that the groups may use as much as their designs require. This amount varies depending on the size of the class.

Vocabulary with Definitions:

Soil- The top layer of the earth's surface, consisting of rock and mineral particles mixed with organic matter.

Filter- A device containing such a material, especially one used to extract impurities from air or water.

Assessment/Evaluation of Students:

Students are graded on participation, final working prototype (low weight) and effort.

Lesson Extensions:

http://www.jhu.edu/~gazette/2004/30aug04/30river.html

-The above link is an excellent article about riverbed filtration research done by people at John Hopkins University.

Safety Issues:

Teachers should pre-cut the 2 liter bottles as to avoid accidents with scissors and burs.

IV
H

Lesson Title: Forces exerted on a paper airplane

Grade Level: 4^{th}

Lesson Time: 40-50 minutes

Instructional Mode: Large Group

Team/ Group Size: 2-4 students

Summary: Students will design and construct a paper airplane capable of flying at least ten feet. The goal of this lesson is to teach the students about forces acting on an airplane during flight.

Learning Objectives:

2004 Worcester Public Schools Benchmarks for 4^{th} Grade

Skills of Inquiry

Students Will…

04.SC.IS.01	Ask questions and make predictions that can be tested.
04.SC.IS.03	Keep accurate records while conducting simple investigations or experiments.
04.SC.IS.04	Conduct multiple patterns in data to test a prediction. Compare the results of an investigation or experiment with prediction.
04.SC.IS.06	Record data and communicate findings with others using graphs, charts, maps, models, and oral and written reports.

Technology/Engineering

Students Will…

04.SC.TE.01	Identify materials used to accomplish a design task based on specific property.
04.SC.TE.02	Identify and explain the appropriate materials and tools to construct a given prototype safely.
04.SC.TE.06	Identify relevant design features for building a prototype of a solution to a given problem.

Essential Questions:

What are the four forces acting on an airplane?
What is weight?
What is lift?
What is thrust?
What is drag?

Procedure:

1. Introduce the students to the activity.
2. Show the children how to make a "basic" paper airplane.
3. Describe the forces acting on an airplane using the basic paper airplane you have made.
4. Hand out materials; 1 sheet of paper per student and tape.
5. Have students draw a rough sketch of what their airplane will look like.
6. Have each student in the group to make a prototype of an airplane.
7. Test the individual airplanes.
8. Record distance data.
9. Allow the group to discuss their findings in the individual airplane launching to come up with a final design for the group airplane. Sketch design.
10. Hold a competition to see that all group's designs go at least ten feet and which group's design goes the furthest.

Materials:

1 sheet of paper per student
1 sheet for the whole group
tape (1 roll for the whole class)

Vocabulary with Definitions:

Force- A push or a pull on an object.

Lift- A force exerted on an airplane wing which causes the airplane to rise.

Thrust- A force produced by an engine that drive an airplane or rocket forward.

Drag- A force due to air resistance which slows a plane down.

Weight- The force that pulls objects to the surface of the earth.

Assessment/Evaluation of Students: Graded on worksheet, participation, final product and effort.

Troubleshooting Tips:

Show student how to make a basic paper airplane, however, encourage "out-of-the-box" thinking.
Explain that throwing your plane harder may not actually make it go further.
Ask the students to wave their hand in the air to experience drag.
Ask if the students have ever stuck their hand out of a window in a car. Describe how the different forces you feel when you stick your hand out of a car coincide with the forces that act on an airplane.

Safety Issues:

Have a separate area for throwing the paper airplanes so that nobody gets hit mistakenly. Care should always be taken when projectiles are in use.

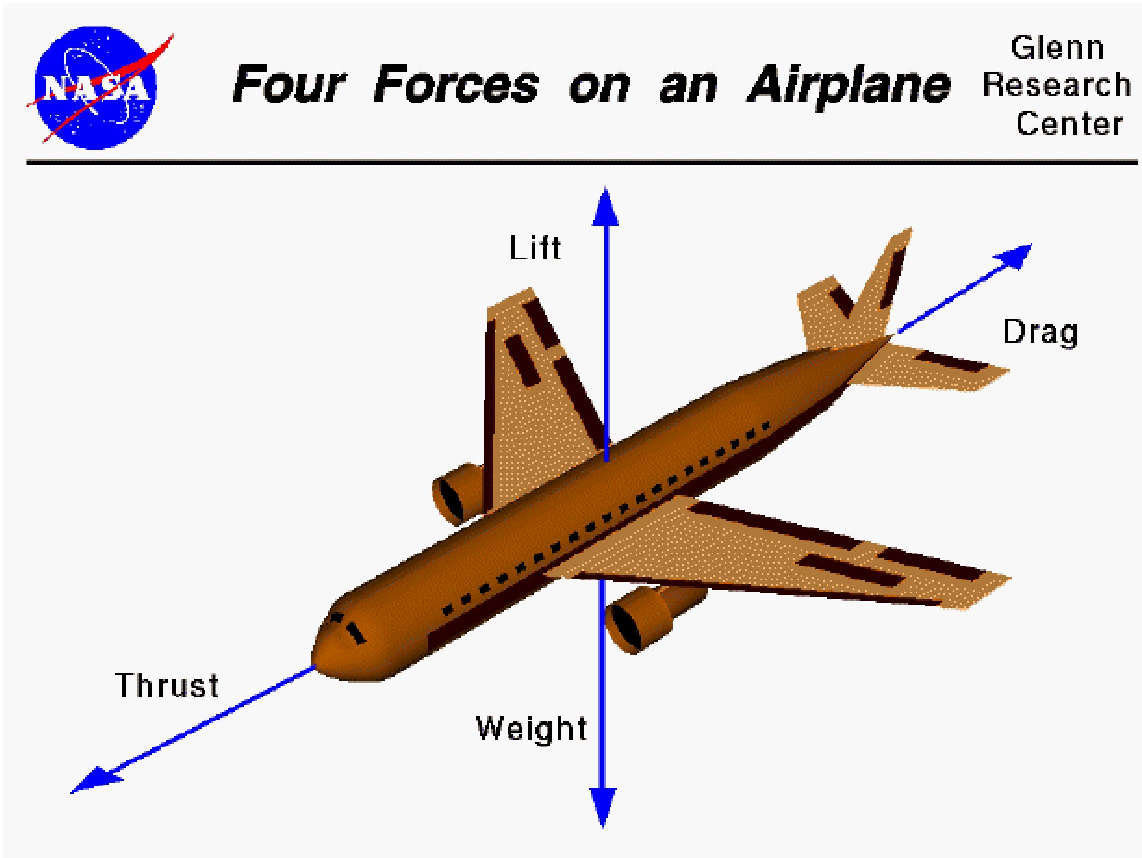


Figure 14: Forces on an Airplane

Photo compliments of the National Aeronautics and Space Administration (NASA) http://www.grc.nasa.gov/WWW/K-12/airplane/forces.html

Name________________________

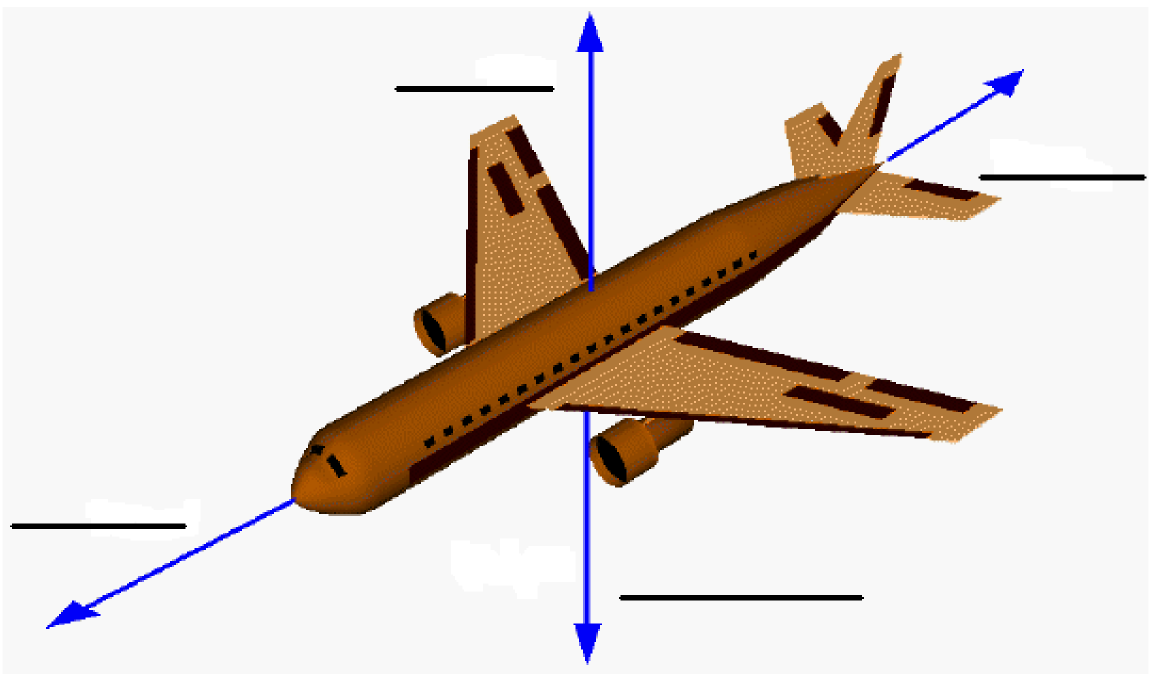
Date____________

What are the Forces on an Airplane?

Label the Forces on the correct arrows

Vocabulary:

Thrust Drag Weight Lift



True or False?

T or F

_____ If you throw a paper airplane harder, it will always go further.

IV
I

Lesson Title: Environmental Creations

Grade Level: 4^{th}

Instructional Mode: Large Group

Team/ Group Size: 2

Summary: The student will create a plant or animal that is fictional. The animal and or plant must somehow help the environment. Students must create and describe all aspects of the creature or plant. Explain the background to the creature or plant, color, size shape, etc… Everything they make will be created from their own imaginations, there are no wrong ways to do this project.

Learning Objectives:

2004 Worcester Public Schools Benchmarks for 4^{th} Grade

Skills of Inquiry

Students will…

04.SC.IS.01	Ask questions and make predictions that can be tested.
04.SC.IS.02	Select and use appropriate tools and technology (e.g., calculators, computers, balances, scales, meter sticks, graduated cylinders) in order to extend observations.
04.SC.IS.03	Keep accurate records while conducting simple investigations or experiments.
04.SC.IS.05	Recognize simple patterns in data and use data to create a reasonable explanation for the results of an investigation or experiment.
04.SC.IS.06	Record data and communicate findings to others using graphs, charts, maps, models, and oral and written reports.

Life Science

Students will…

04.SC.LS.03	Differentiate between observed characteristics of plants and animals that are fully inherited (e.g., color of flower, shape of leaves, color of eyes, number of appendages) and characteristics that are affected by climate or environment (e.g., browning of leaves due to too much sun, biorhythms).
04.SC.LS.05	Give examples of how inherited characteristics may change over time as adaptations to change in the environment that enable organisms to survive(e.g., shape of beak or feet, placement of eyes on head, length of neck, shape of teeth, color).

04.SC.LS.06	Compare and contrast the physical characteristics of plants or animals from widely different environments (desert vs. tropical plants; aquatic vs. terrestrial animals
04.SC.LS.07	Give examples of how changes in the environment (drought, cold) have caused some plants and animals to die or move to new locations (migration).
04.SC.LS.08	Investigate how invasive species out-compete native plants (e.g., phragmites and purple loose-strife). Discuss how some native plants die as a result.

Technology & Engineering

Students will…

04.SC.TE.01	Identify materials used to accomplish a design task based on specific properties
04.SC.TE.04	Identify a problem that reflects the need for shelter, storage or convenience.
04.SC.TE.05	Describe the different ways in which a problem can be represented (e.g., sketches, diagrams, graphic organizers and lists).
04.SC.TE.06	Identify relevant design features (e.g., size, shape, weight) for building a prototype of a solution to a given problem.

Essential Questions:

What kind of creature have you created?

Where does the creature live, eat, etc…

Procedure:

1. Students will collaborate to describe a creature or plant.
2. They will then draw a color picture of their creations and then label all of its parts.
3. Students will then present their creations in front of the class as if they were salespeople.

Materials:

-White Paper (one sheet initially, more for mistakes)

-Crayons, Markers and/or Colored Pencils (1 box per group)

-Construction paper (White paper alternative)

-Glue (1 stick per group)

Vocabulary with Definitions:

Environment: ĕn-vīʹrən-mənt, -vīʹərn-) *n.*

1. The circumstances or conditions that surround one; surroundings.
2. The totality of circumstances surrounding an organism or group of organisms, especially:

a. The combination of external physical conditions that affect and influence the growth, development, and survival of organisms: “We shall never understand the natural environment until we see it as a living organism” (Paul Brooks).
b. The complex of social and cultural conditions affecting the nature of an individual or community.

<u>Growth:</u> (grōth) *n.*

1.
    a. The process of growing.
    b. Full development; maturity.
2. Development from a lower or simpler to a higher or more complex form; evolution.

<u>Inheritance:</u> (ĭn-hĕrˈĭ-təns) *n.*

1.
    a. The act of inheriting.
    b. Something inherited or to be inherited.
2. <u>*Biology.*</u>
    a. The process of genetic transmission of characteristics from parents to offspring.
    b. A characteristic so inherited.
    c. The sum of characteristics genetically transmitted from parents to offspring.

<u>Migration:</u> (mī-grāˈshən) *n.*

1. The act or an instance of migrating.
2. A group migrating together.
3. <u>*Chemistry & Physics.*</u>
    a. The movement of one atom or more from one position to another within a molecule.
    b. The movement of ions between electrodes during electrolysis.

<u>Territorial:</u> (tĕrˌĭ-tôrˈē-əl, -tōrˈ-) *adj.*

1. Of or relating to the geographic area under a given jurisdiction: *the territorial limits of a country.*
2. Relating or restricted to a particular territory; regional: *a territorial court.*
3. often **Territorial** Of or relating to an administrative territory: *the territorial government of the U.S. Virgin Islands; Whitehorse, the territorial capital of the Yukon.*

4. often **Territorial** Organized for national or home defense: *the British Territorial Army*.
5. *Biology.* Displaying territoriality; defending a territory from intruders: *territorial behavior; a territorial species.*

Life cycle: *n.*

1. The course of developmental changes through which an organism passes from its inception as a fertilized zygote to the mature state in which another zygote may be produced.
2. A progression through a series of differing stages of development.

Source: www.dictionary.com

Assessment/Evaluation of Students: Graded on drafts, participation and presentation.

Troubleshooting Tips:

Encourage the students to be creative. Make sure you do not stifle their ideas, nothing is wrong. Just make sure you help them create something that can help the environment.

IV
J

Lesson Title: Small Structure Part II

Grade Level: 4th

Instructional Mode: Large Group

Team/ Group Size: 3-4

Summary: The students will review what they have learned about Civil Engineering and The 5 Keys to Building a Strong, Lightweight Structure. Before building, the students will complete the engineering design report. Then the students will create the prototype of the frame that they voted to be the better design amongst their group from their previous assignment from the Small Structures Part I. The students have until the end of one class period to complete the construction. At the end of the class, they will be handed and homework assignment.

Learning Objectives:

2004 Worcester Public Schools Benchmarks for 4th Grade

Skills of Inquiry

Students will…

04.SC.IS.03	Keep accurate records while conducting simple investigations or experiments.
04.SC.IS.04	Conduct multiple patterns in data to test a prediction. Compare the results of an investigation or experiment with prediction.
04.SC.IS.06	Record data and communicate findings to others using graphs, charts, maps, models, and oral and written reports.

Technology & Engineering

Students will…

04.SC.TE.01	Identify materials used to accomplish a design task based on specific properties
04.SC.TE.04	Identify a problem that reflects the need for shelter, storage or convenience.
04.SC.TE.05	Describe the different ways in which a problem can be represented (e.g., sketches, diagrams, graphic organizers and lists).
04.SC.TE.06	Identify relevant design features (e.g., size, shape, weight) for building a prototype of a solution to a given problem.

MSTECF Standards

Students will…

4.1.1 Identify materials used to accomplish a design task based on a specific property, i.e. weight, strength, hardness, and flexibility.

4.2.3 Identify relevant design features (e.g., size, shape, weight) for building a prototype of a solution to a given problem.

Essential Questions:

Did the structure follow the 5 keys?

How are the shapes within your prototype going to make the structure stronger?

Introduction/Motivation:

Review what was instructed about Civil Engineering (5 Keys to Build a Strong, Lightweight Structure).

Show students pictures of structures from Small Structures Part I on the overhead and discuss the framework and why it is strong.

Procedure:

1) Groups must vote on better design from the previous homework assignment
2) Pass out materials (craft sticks, tape)
3) Create Prototype
4) Pass out homework assignment

Materials (per group):

Found on handout from *Small Structures I*

25 Craft Sticks

60 cm of tape

Assessment/Evaluation of Students:

Handout assessment

Attachments:

1. Engineering paper
2. Engineering design report
3. 5 keys to building a strong lightweight structure
4. Worksheet/Homework
5. Prototype sheet

Troubleshooting Tips:

Warn students of their material limitations to keep them from running out of materials with their project half done.

Key Words: Civil Engineering, Small Structures, Studs, Joists, Truss, Headers, Beams.

Name__________________________ **Date**_____________

Engineering Paper

Draw a picture of a building near you. This could be any kind of real building such as a house, gas station, grocery store, or sky scraper. Label all of the strong parts of the building and show how it is protected by wind and rain.

Engineering Design Report

Group Members:

Step 1: What is the problem? ________________________________

What is the goal of your solution? ____________________________

Step 2: How did you research the problem? Summarize your findings.

Step 3: Brainstorm. Write down your ideas on your Engineering Paper.

5 Keys to Building a
Strong, Lightweight Structure

1.) Start with a wide base.

2.) Design with triangles, instead of rectangles.

3.) Use trusses instead of beams.

4.) Add braces to reinforce weak areas.

5.) Make weak areas thicker

Name: ______________ Date: ________

5 Keys to Building a Strong, Lightweight Structure

Directions: Complete each sentence by filling in the blank. Choose from the list of words at the bottom of the page. Use each word only once.

Start with a wide _____________.

Use ____________ instead of squares.

Build with _____________ for long, straight pieces.

Add _____________ to make weak corners stronger.

Make weak pieces ____________.

thicker	triangles
base	trusses
braces	

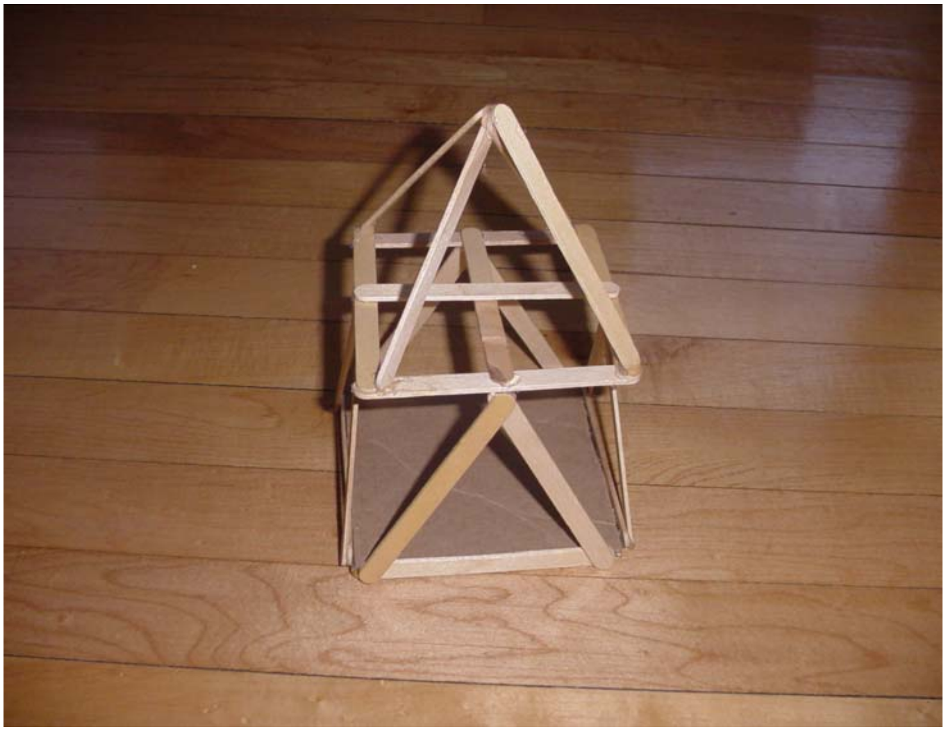


Figure 15: Small Structure with Base

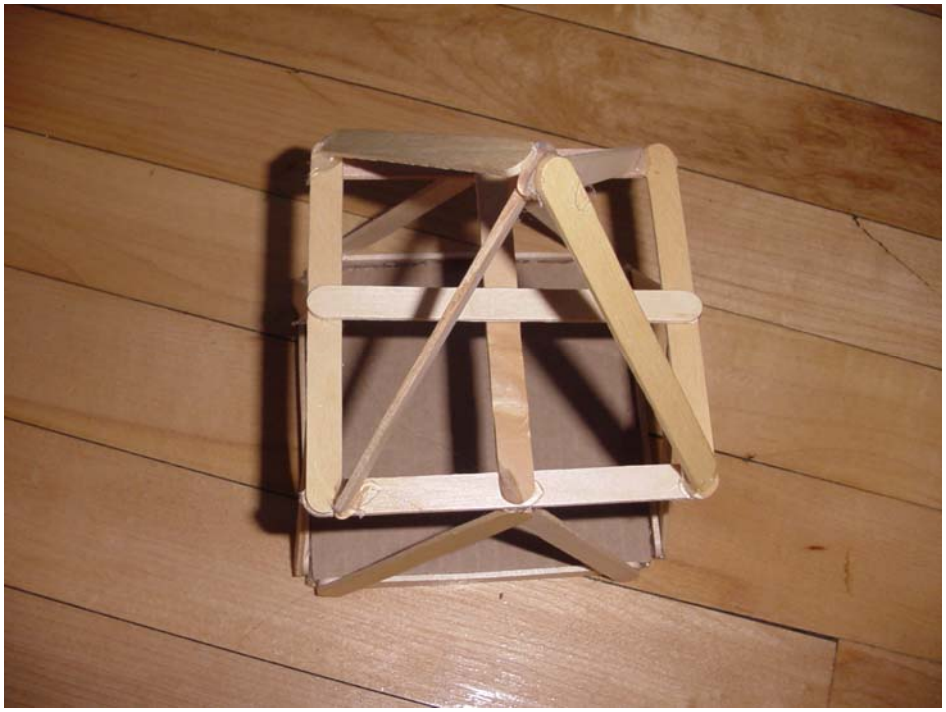


Figure 16: Top of Small Structure

http://www.wpi.edu/Academics/PIEE/Resources/Lessons/4tecranel2.pdf

IV
K

Lesson Title: Small Structure Part III

Grade Level: 4^{th}

Instructional Mode: Large Group

Team/ Group Size: 2-3

Summary: Students will use the material they are given to complete their prototype by adding walls and a roof. Student will then have their prototypes tested against rain and wind. The teacher will set up and test the prototypes using a spray bottle, and fan.

Learning Objectives:

2004 Worcester Public Schools Benchmarks for 4^{th} Grade

Skills of Inquiry

Students will…

04.SC.IS.03	Keep accurate records while conducting simple investigations or experiments.
04.SC.IS.04	Conduct multiple patterns in data to test a prediction. Compare the results of an investigation or experiment with prediction.
04.SC.IS.06	Record data and communicate findings to others using graphs, charts, maps, models, and oral and written reports.

Technology & Engineering

Students will…

04.SC.TE.01	Identify materials used to accomplish a design task based on specific properties
04.SC.TE.04	Identify a problem that reflects the need for shelter, storage or convenience.
04.SC.TE.05	Describe the different ways in which a problem can be represented (e.g., sketches, diagrams, graphic organizers and lists).
04.SC.TE.06	Identify relevant design features (e.g., size, shape, weight) for building a prototype of a solution to a given problem.

MSTECF Standards

Students will…

4.1.1	Identify materials used to accomplish a design task based on a specific property, i.e. weight, strength, hardness, and flexibility.
4.2.3	Identify relevant design features (e.g., size, shape, weight) for building a prototype of a solution to a given problem.

Essential Questions:

What is the purpose of a roof/wall?
What material should you use to build a roof/wall?
What materials can withstand rain/wind?

Introduction/Motivation:

Small Structures II

Procedure:

1. Pass out prototypes
2. Pass out materials (paper, plastic, tape)
3. Test prototypes
    a. Using a plastic bin or towel, test the prototypes against rain by spraying them with a spray bottle
    b. Using a fan, try to tip over the prototypes. If the bases (1^{st} key) are large enough they should not tip over.

Materials:

-Plastic sheets (3-8x11 sheets)
-Construction Paper (3-8x11 sheets)
-Tape (one roll per class)
-Fan (any size with a decent amount of flow)
-Towel or plastic bin
-Cardboard (from old cereal boxes or leftover shipment boxes)

Assessment/Evaluation of Students: See Attachment

Attachments: Evaluation Sheet

Safety Issues:

Have an adult operate the fan.

Key Words: Civil Engineering

HOMEWORK

Name: ______________________________

What are the 5 Keys to building a strong, safe structure?

1. ____

2. ____

3. ____

4. ____

5. ____

Did your design pass the rain test?

Yes No

Did your design pass the wind test?

Yes No

If you could design and build a structure again, what improvements or changes would you make?

____

____

____

____

____

____

____

____

IV
L

Lesson Title: Simple Machines 2

Grade Level: 4th

Instructional Mode: Large Group

Group Size: Whole Class

Summary: One of the basic fundamentals of engineering is the use of simple machines. In this exercise, students will move a book up a flight of stairs without the use of their bodies. (IE students will utilize simple machines to move the book.)

Learning Objectives:

2004 Worcester Public Schools Benchmarks for 4th Grade

<u>Skills of Inquiry</u>

Students will…

- 04.SC.IS.01: Ask questions and make predictions that can be tested.
- 04.SC.IS.03: Keep accurate records while conducting simple investigations or experiments.
- 04.SC.IS.06: Record data and communicate findings to others using graphs, charts, maps, models, and oral and written reports.

<u>Technology & Engineering</u>

Students will…

- 04.SC.TE.01: Identify materials used to accomplish a design task based on a specific property (e.g., weight, strength, harness, and flexibility.)
- 04.SC.TE.02: Identify and explain the appropriate materials and tools (e.g., hammer, screwdriver, pliers, tape measure, screws, nails, and other mechanical fasteners) to construct a given prototype safely.
- 04.SC.TE.03: Identify the difference between simple and complex machines (e.g., hand can opener that includes multiple gears, wheel, wedge gear, and lever.)
- 04.SC.TE.05: Describe different ways in which a problem can be represented (e.g., Sketches, diagrams, graphic organizers, and lists.)
- 04.SC.TE.08: Apply the metric system in design projects and experiments.

<u>MSTECF Standards</u>

Students will…

4.1.1	Identify materials used to accomplish a design task based on a specific property, i.e. weight, strength, hardness, and flexibility.
4.1.2	Identify materials used to accomplish a design task based on a specific property, i.e., weight, strength, hardness, and flexibility.
4.1.3	Identify and explain the difference between simple and complex machines, e.g., hand can opener that includes multiple gears, wheel, wedge gear, and lever.
4.2.1	Identify a problem that reflects the need for shelter, storage, or convenience.
4.2.2	Describe different ways in which a problem can be represented, e.g., sketches, diagrams, graphic organizers, and lists.

Essential Questions:

What accommodations are made for handicapped people in our community?

Introduction/Motivation:

The objective of this lesson is to have students understand how simple machines can impact our everyday life. By using a combination of the simple machines, students can design and build a hands free system that will take a book up a flight of stairs.

Ideally, students will use an inclined plane, pulley, and a cart with wheels to pull the book up the flight of stairs. (See diagram for information)

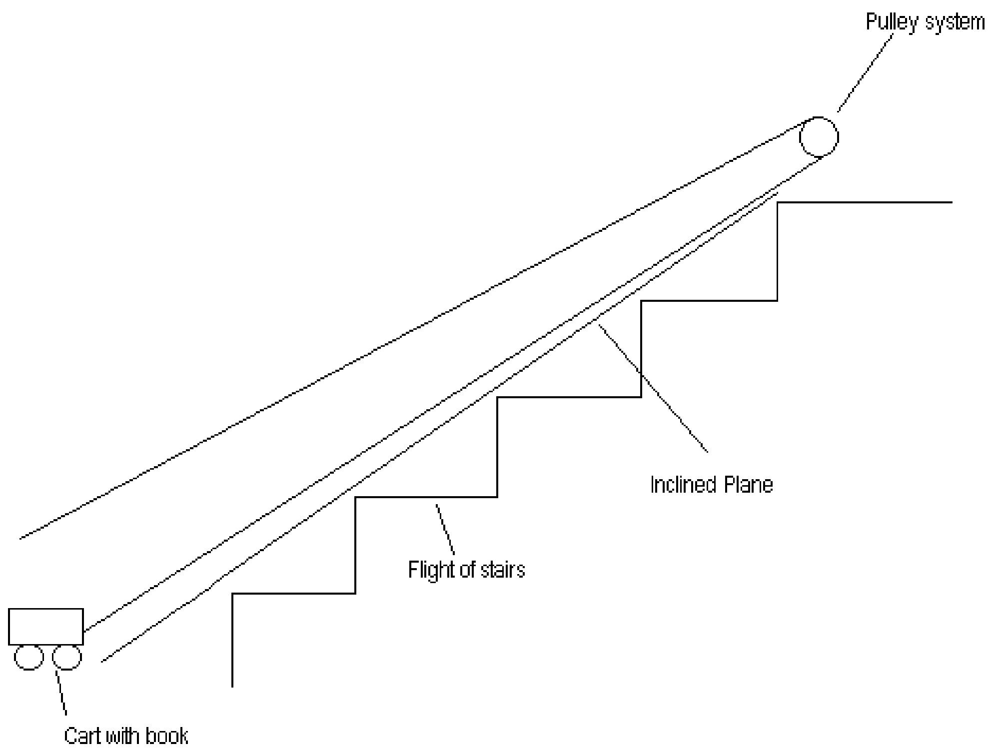


Figure 17: Simple Pulley System

Procedure:

Students will brainstorm for 10-15 minutes on solutions to problem. After, assemble near a stairwell, and try out the given solution.

Vocabulary:

Wedge- Two inclined planes joined back to back. Wedges are used to split things.

Inclined plane- A plane set at an angle to the horizontal, used to raise or lower a load by rolling or sliding.

Lever- A bar that turns about a pivot point (the fulcrum) and is used to transfer and/or multiply force.

Pulley- A wheel with a grooved rim in which a pulled rope or chain can run to change the direction of the pull and thereby lift a load. Work is made easier because pulling down on the rope is made easier due to gravity.

Wheel and axle- A simple machine consisting of an axle to which a wheel is fastened so that torque applied to the wheel winds a rope or chain onto the axle, yielding a mechanical advantage equal to the ratio of the diameter of the wheel to that of the axle. (When the axle is turned, the wheel moves a greater distance than the axle, but less force is needed to move it. The axle moves a shorter distance, but it takes greater force to move it.)

Assessment/Evaluation of students:

Ability to work as a group, participation, presentation of findings to class.

Lesson extensions:

A game found on the web:
http://edheads.org/activities/simple-machines/
Click on the robot that says "Click here to start!"
If computers are not available, this lesson extension is not necessary.

Troubleshooting tips: Students may assist in the lesson; but may work incorrectly if pulled too quickly/forcefully.

Redirect URL: http://www.yale.edu/ynhti/curriculum/units/2003/4/03.04.05.x.html#d

Key Words: Simple machines, complex machines

IV
M

Lesson Title: Shoebox Racers

Grade Level: 4th

Instructional Mode: Large Group

Team/ Group Size: 2

Time: 2 hours (2 class periods. Can be split up)

Summary: The objective is to have to students use their knowledge of simple machines by engineering a car with the option of using different amount of wheels. This lesson is to exercise their original ideas and to give the students a clearer understanding of the wheel and axel.

Learning Objectives:

2004 Worcester Public Schools Benchmarks for 4th Grade

Skills of Inquiry

Students Will…

04.SC.IS.01	Ask questions and make predictions that can be tested.
04.SC.IS.02	Select and use appropriate tools and technology
04.SC.IS.03	Keep accurate records while conducting simple investigations or experiments.
04.SC.IS.04	Conduct multiple patterns in data to test a prediction. Compare the results of an investigation or experiment with prediction.
04.SC.IS.06	Record data and communicate findings with others using graphs, charts, maps, models, and oral and written papers

Technology/Engineering

Students Will…

04.SC.TE.01	Identify materials used to accomplish a design task based on specific property.
04.SC.TE.02	Identify and explain the appropriate materials and tools to construct a given prototype safely.
04.SC.TE.02	Identify and explain the difference between simple and complex machines.
04.SC.TE.06	Identify relevant design features for building a prototype of a solution to a given problem.
04.SC.TE.08	Apply the metric system in design projects and experiments.

Essential Questions:

What is the purpose of a wheel and axle?
If I added more wheels to something, would it be easier to move it? Why?

Introduction/Motivation:

Show the students pictures of different vehicles with different amounts of wheels on them.
Show the students an original prototype of your own (or a picture).
.

Procedure:

1) Students will receive a hand out with a materials list and design paper which they will bring home for an assignment. Each group will decide which design is better to build via design matrix.
2) One group member should bring a shoebox from home. Students will build a car using their designs. Each group is assigned a number which they will place on their car.
    a. To make the holes for the wheels, use a hole punch
3) Students will show their car and describe the key features then they can test their prototypes by rolling them down a ramp made from a piece of cardboard and stacked books.
4) Students will then receive a conclusion handout which will be assigned for homework.

Materials:

- Wooden Dowels (1/4 inch, 1 per group)
- Wheels (bottoms of paper cups, use different sizes)
- Tape (1 roll)
- Shoebox (students must produce their own)
- Scissors (1 pair per group)
- Elastic Bands (10 per group to be safe)
- Construction Paper (2-4 sheets per group)
- Hole Punch (1 per class)
- Ramp (cardboard and stacked books 3'x1')

Vocabulary with Definitions:

Simple Machines- a device for overcoming resistance at one point by applying force at some other point.

Wheel and axle- A solid disk or a rigid circular ring connected by spokes to a hub, designed to turn around an axle passed through the center. Forces that provide energy, movement, or direction.

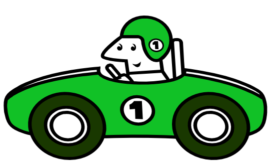
Source: www.dictionary.com

Assessment/Evaluation of Students: Graded on drafts, participation and presentation, and assignments.

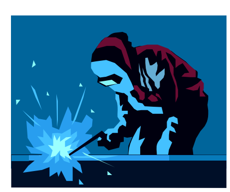
Lesson Extensions: Possibly a gravity and momentum lesson could be used after this lesson if it is appropriate for the class.

Attachments: Materials List, Worksheet, Design Paper, Conclusion Page

Key Words: Simple machines, Wheel and Axle, Shoebox



Shoebox Racer



Build your own car!!! But first…

Tell me 3 things you know about the WHEEL AND AXLE.

Other than a car, where else can you find a WHEEL AND AXLE?

Here's the scoop, you have these materials and you are going to design a car on the paper provided and with only these materials. You can use up to 10 wheels total. You cannot change the shape of the box. The car must be VERY colorful and original. You and your teammate will decide which design you will build in the next class.

Materials:

Wooden dowels	**Wheels**	**1 Shoebox**
Tape	**Elastic Bands**	**Glue**
Construction Paper	**Markers**	

Don't forget to bring your shoebox!!!

Design Paper

Be creative and build it to scale. Be colorful and original!!!
On the back of this paper, create a design matrix with you and your partner's designs. Then vote on the better design.

Name________________

What did you learn?

Which car ran the best?

What were the sizes of the wheels?

What advantages do larger wheels have to smaller wheels? What disadvantages do the larger wheels have to smaller wheels?

Is it safer? Why?

What can you change in your prototype that could make it better?

On a separate piece of paper, please re-draw your new prototype and explain what you changed and how it will make it better.

IV
N

Lesson Title: Mini-cars and simple forces off a ramp

Grade Level: 4th

Lesson time: One day for background, one day for game

Instructional Mode: Small groups

Team/Group Size: 2 students

Summary: Students will build cars out of Legos and launch them off a ramp to see how far they can get them to fall off a table and survive.

Learning Objectives:

2004 Worcester Public Schools Benchmarks for 4th Grade

Skills of Inquiry

Students Will…

04.SC.IS.01	Ask questions and make predictions that can be tested.
04.SC.IS.03	Keep accurate records while conducting simple investigations or experiments.
04.SC.IS.04	Conduct multiple trials to test a prediction. Compare the results of an investigation or experiment with the prediction.
04.SC.IS.05	Recognize simple patterns in data and use data to create a reasonable explanation for the results of an investigation or experiment.
04.SC.IS.06	Record data and communicate findings to others using graphs, charts, maps, models, and oral and written reports.

Physical Science

Students Will…

04.SC.PS.0	Give examples of how energy can be transferred from one form to another.

Technology/Engineering

Students Will…

04.SC.TE.01	Identify materials used to accomplish a design task based on a specific property (e.g., weight, strength, harness, and flexibility.)
04.SC.TE.05	Describe different ways in which a problem can be represented (eg., Sketches, diagrams, graphic organizers, and lists.)

04.SC.TE.08 Apply the metric system in design projects and experiments.

Essential Questions:

What is the best Lego car structure to use to survive a far drop?

Introduction/Motivation: Have your students understand the distance the car can fly off the table depends on the size, shape, and weight of their car.

Procedure-

-First make sure the students understand the vocabulary.
-Have each student prepare a preliminary drawing of their car, with all parts labeled and shown.
-Each group will be given 4 wheels and the rest of the construction is up to them.
-The students will be give the choice of materials from a large box of Legos.
-They will be given two chances to test their vehicles and make modifications before everyone's vehicles will be put against each other.

Vocabulary with Definitions-

Gravity- (grăvʹĭ-tē)*n.*

1. *Physics.*
    a. The natural force of attraction exerted by a celestial body, such as Earth, upon objects at or near its surface, tending to draw them toward the center of the body.
    b. The natural force of attraction between any two massive bodies, which is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.
    c. Gravitation.
2. Grave consequence; seriousness or importance: *They are still quite unaware of the gravity of their problems.*
3. Solemnity or dignity of manner.

Force-(fôrs, fōrs)*n.*

1. The capacity to do work or cause physical change; energy, strength, or active power: *the force of an explosion.*
2.
    a. Power made operative against resistance; exertion: *use force in driving a nail.*
    b. The use of physical power or violence to compel or restrain: *a confession obtained by force.*
3.
    a. Intellectual power or vigor, especially as conveyed in writing or speech.
    b. Moral strength.

   c. A capacity for affecting the mind or behavior; efficacy: *the force of logical argumentation.*
   d. One that possesses such capacity: *the forces of evil.*
4.
   a. A body of persons or other resources organized or available for a certain purpose: *a large labor force.*
   b. A person or group capable of influential action: *a retired senator who is still a force in national politics.*
5.
   a. Military strength.
   b. The entire military strength, as of a nation. Often used in the plural.
   c. A unit of a nation's military personnel, especially one deployed into combat: *Our forces have at last engaged the enemy.*
6. Law. Legal validity.
7. Physics. A vector quantity that tends to produce an acceleration of a body in the direction of its application.
8. Baseball. A force play.

Acceleration-(ăk-sĕl'ə-rā'shən)*n.*

1.
   a. The act of accelerating.
   b. The process of being accelerated.
2. *Abbr.* **a** Physics. The rate of change of velocity with respect to time.

Velocity-(və-lŏs'ĭ-tē)*n. pl.* **ve·loc·i·ties**

1. Rapidity or speed of motion; swiftness.
2. Physics. A vector quantity whose magnitude is a body's speed and whose direction is the body's direction of motion.
3.
   a. The rate of speed of action or occurrence.
   b. The rate at which money changes hands in an economy.

Source: www.dictionary.com

Assessment/Evaluation of students-
Ability to work as a group, participation, presentation of findings to class.

Safety Issues- Make sure they do not swallow the Legos.

IV
O

Lesson Title – Animal and Plant Adaptation

Grade Level – 4^{th}

Lesson Time – 1 class periods

Instructional Mode – Lecture, Demonstration, and Small Group Activity

Team/Group Size – 2 large groups

Summary – The students will learn about the types of adaptation and play the "adaptation game".

Learning Objectives –

2004 Worcester Public Schools Benchmarks for 4^{th} Grade

Life Science

Students Will…

04.SC.LS.03	Differentiate between observe characteristics of plants and animals that are fully inherited (e.g., eye color, hair color, earlobe free or attached)
04.SC.LS.05	Give examples of how inherited characteristics may change over time as adaptations to changes in the environment that enable organisms to survive (eg shape of beak or feet, placement of eyes on head, length of neck, shape of teeth, color.)
04.SC.LS.06	Compare and contrast the physical characteristics of plants or animals from widely different environments. Explore how each is adapted to its habitat.

Essential Questions –

What is adaptation?
Can you name an animal that has to adapt to an environment in order to survive?
How about a plant?

Introduction / Motivation –

Ask the students the following questions:

- Why do animals need to adapt?
    - You should get the following responses (or lead the students to the following answers):
        - Weather
        - Food
        - Protection from predators

- If I were to move you to the North Pole, what would you need to do in order to survive?
- Have the class read the overhead page about penguins out loud and then ask them what it means and how they can relate it to adaptation.
- Show the students the overhead with the different animals and plants and ask the students what important traits they have that are a form of adaptation and what it is used for.

Procedure –

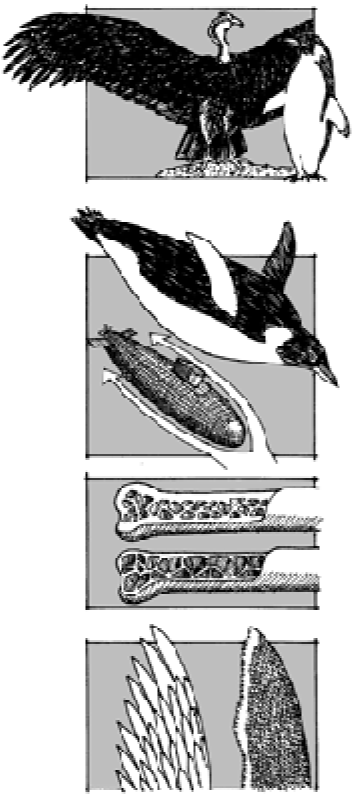
1. Split the students up into 2 large groups naming them Team A and Team B. One student will be the spokesperson.
2. Place the adaptation cards into a bag, hat, or a bowl.
3. One student from Team A will come up and pick a card then they will have 1 minute to draw a picture of the adaptation (**In bold on the card)** on the board. Team A (excluding the teammate drawing) will have to conference their answer within the minute that the picture is drawn. At the end of the minute, one student will give an answer of the picture and an animal/plant that exhibits this adaptation. If they are right, they will earn 2 points. They can earn an extra point if they can say why the animal/plant needs this adaptation.
4. If Team A does not have the right answer, then Team B will have the chance for a "steal". Team B will have to give an immediate answer so they must be conferencing while the picture is being drawn. They can earn up to one point for the steal and an extra point if they can say why the animal/plant needs this adaptation. If both teams do not have a correct answer, then no points will be awarded.
5. The teams will alternate the picture drawings.

Vocabulary with Definitions-
Adaptation- An alteration or adjustment in structure or habits, often hereditary, by which a species or individual improves its condition in relationship to its environment.

Assessment/Evaluation of Students – Participation

Attachments – Penguin overhead. Adaptation cards

Key Words – Adaptation, cards



Penguin Adaptation

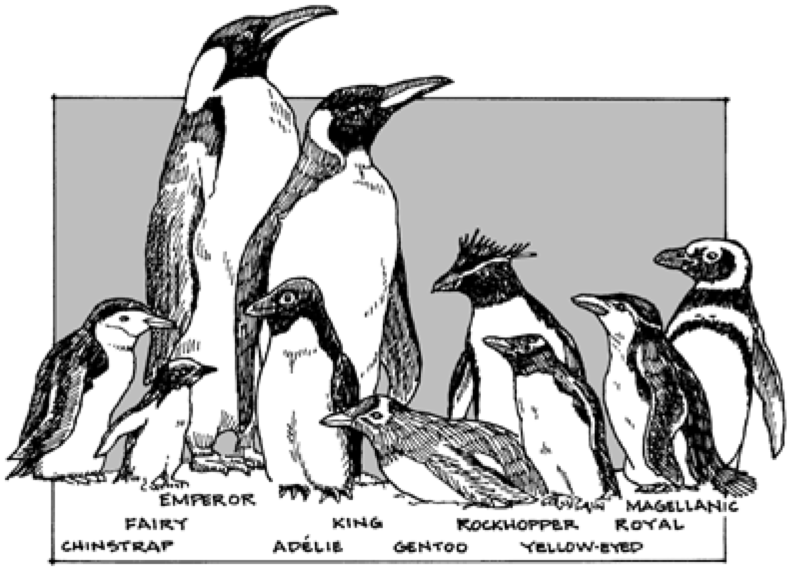


Figure 18: Penguin Classes

Penguins are designed for life in the sea. Some species spend as much as 75% of their lives in the water. (They lay their eggs and to raise their chicks on land.) Heavy, solid bones act like a diver's weight belt, allowing them to stay underwater. Their wings, shaped like flippers, help them "fly" underwater at speeds up to 15 mph. A streamlined body, paddle-like feet, insulating blubber, and watertight feathers all add to their efficiency and comfort underwater. They also have a remarkable deep-diving ability.

In addition to blubber for insulating warmth, penguins have stiff, tightly packed feathers (up to 70 per sq. in.) that overlap to provide waterproofing. They coat their feathers with oil from a gland near the tail to increase impermeability. Black and white countershading makes them nearly invisible to predators from above and below.

Like most birds, penguins have little or no sense of smell (a boon for those in a crowded penguin rookery!) Like other birds, their sense of taste is also limited. Their vision appears to be better when they are underwater. Scientists suspect they may be nearsighted on land.

Penguins are considered to be the most social of birds. Rookeries may contain thousands of individuals. (As many as 24 million penguins visit the Antarctic continent!) Even at sea, they tend to swim and feed in groups. Most species of penguins build nests, but the nests may consist only of a pile of rocks or scrapings or hollows in the dirt. Emperor penguins build no nests; they hold the egg on top of their feet under a loose fold of skin called the brood patch. http://octopus.gma.org/surfing/antarctica/penguin.html

Table 16: Traits of Animals

Exoskeleton (Shell) Protection from enemies. Protects from drying out. Waterproof	**Stingers** For protection Bees Wasps	**Eyespots** (on wings) Butterflies; to scare off enemies	**Slimy Skin** Frogs, Salamanders Protects from drying out	**Poison Glands** Toads Protection from enemies
Long Legs Escape predators. Reach food in high places	**Horns** Defense. Mating displays	**Whiskers** Help to feel environments (in the dark)	**Thick Stems** Cactus; hold in moisture in the dry climates	**Seeds blow in wind** Dandelions, Grass; help spreading growth.
Large canine teeth Dogs, cats; Help to kill prey	**Webbed feet** Ducks; used for swimming and walking in mud	**Long hair/fur** To keep warm in cold climates	**Long sharp claws** Cats; help climb trees. Help to escape predators	**Bright colors** Fish; used for attracting mates

Figure 19: Black Bear

http://estes.on-line.com/wildwatch/Bear.html

Figure 20: Heron

http://www.photo.net/photo/pcd1641/bird-fancy-grey-93.tcl

Figure 21: Cactus

http://www.life.umd.edu/cbmg/faculty/acaines/bsci124/extracreditplants.html

Figure 22: Snake

sfghed.ucsf.edu/ ClinicImages/Coral%20snake.jpg

Figure 23: Octopus

fusionanomaly.net/ octopus.jpg

Figure 24: Matured Dandelion

http://www.theherbspecialist.com/herbphotos/dandelion.jpg

IV
P

Lesson Title – Adaptation and Migration

Grade Level – 4th

Lesson Time – Two sessions of 45 minutes

Instructional Mode – entire class

Team/Group Size – 2-4 students

Summary – In this lesson, students will be given materials for research, present their findings to the class, and make an adjustment to the animal if the animal had to come and live in Worcester.

Learning Objectives –

2004 Worcester Public Schools Benchmarks for 4th Grade
Life Science
Students Will…

04.SC.LS.03	Differentiate between observe characteristics of plants and animals that are fully inherited (e.g., eye color, hair color, earlobe free or attached)
04.SC.LS.05	Give examples of how inherited characteristics may change over time as adaptations to changes in the environment that enable organisms to survive (eg shape of beak or feet, placement of eyes on head, length of neck, shape of teeth, color.)
04.SC.LS.07	Give examples of how changes in the environment (drought, cold) have caused some plants and animals to die or move to new locations (migration).

Essential Questions –

What kind of adaptation does your animal use?
What kind of adaptations have humans made for our environments?

Introduction / Motivation – Students will be researching an animal assigned by the instructor.

Procedure –

Session 1

1. Have students research a given animal (They should focus on how animals have developed mechanisms to cope with their surroundings, or how animals migrate/hibernate to survive winter). For ideas for animals, see attachments.
2. Have students begin making a poster (the may include drawings and facts)

Session 2

3. Have students complete their posters & prepare a 5 minute presentation
4. Have the students present their findings to the class.
5. During the presentations, have the students take notes. They will need this information for the next lesson.

Materials List (per group) **–**

- Poster for presentation (1 per group)
- Markers (1 pack per group)
- Paper (3 sheets per student)
- Crayons (1 box per group)
- Photocopies if needed (at your discretion)

Vocabulary with Definitions-

Adaptation- 1.An alteration or adjustment in structure or habits, often hereditary, by which a species or individual improves its condition in relationship to its environment. 2. Change in behavior of a person or group in response to new or modified surroundings.

Migrate- To change location periodically, especially by moving seasonally from one region to another.

Different kinds of adaptations:

Camouflage- Where an animal's coat changes color to blend in with surroundings.

Defense- Where an animal's coat or bite defends the animal from predators or allows for protection from harsh climates.

Hibernation- When an animal adapts to harsh winter climates by sleeping through the winter.

Behavioral- Either learned or inherited (instinct); where an animal uses the habit for survival.

Physical- Where the animals body changes to suit its habitat.

Source: www.dictionary.com

Assessment/Evaluation of Students – Presentation of findings to the class

Lesson Extensions – Students could use their animal for the "Build a creature" lesson and adapt their animal to live in Worcester.

Attachments – Worksheets to aid in presentation

Sources-
Redirect URL – http://www.pbs.org/kratts/world/index.html
http://www.uen.org/themepark/habitat/animal.shtml
Game for students to play:
http://www.ecokidsonline.com/pub/eco_info/topics/climate/adaptations/index.cfm

Key Words– adaptation, migration

Animal Information

Animals to choose from: *NOTE* the information after each animal is for instructor use only. The students will research the animal and present their findings to the class.

Snowshoe hare- This animal's fur changes in the winter from brown/grey to white to blend in with the snow.

Canadian Geese- This animal migrates thousands of miles every winter from the Northern US/Canada to the Southern US/Mexico for the warmer climates.

Mole- This animal is designed for digging! It has shovel shaped hands, powerful chests for pushing dirt, and long nails to help it build its home.

Sharks- The shark is infamous for its many teeth, but as one tooth breaks, another one grows in its place. Sharks can go through thousands of teeth in their lifetime.

Frogs- Frogs use their long tongues to catch their prey. Did you know that a frog's eyes do not have orbits? (The area around a human's eye that holds it into place.) When a frog eats a large insect, it can close its eyes and use them to push the prey into their stomachs.

Snakes- These animals hibernate in the winter in order to survive a cold winter and some kinds have poisonous venom to protect them.

Raccoons- In the wild, raccoons live in trees and eat anything from fish to berries. As humans destroyed the raccoons' natural habitats, raccoons changed their habits by living in attics, sheds, and garages. They also have used our garbage cans as their personal buffets.

Camels- Since desert climate is harsh; the camel is able to live for 3-4 days without food or water. (The hump contains fat, NOT water.)

Hummingbirds- These small animals have a long beak which they use to sip nectar from flowers. They also eat small bugs.

Electric Eel- Although not a true eel, this animal defends itself with an organ that can generate electricity. The shock is only 600 V, so it will not kill a person, but repeat shocks will.

Name: ______________________________

Use this worksheet to help you prepare a presentation for the class. After you've completed the worksheet, make a poster with a picture of the animal, and some of the facts you've discovered!

1. What is your animal?

____

2. What adaptations does this animal have to survive in its habitat?

____

____

____

____

____

3. What kind of adaptation does this animal have? (Behavioral, defense, camouflage, physical or hibernation?)

____

____

____

____

____

4. If this animal didn't have these adaptations, what problems would it face?

____

____

____

____

____

IV
Q

Lesson Title: How a Greenhouse Works

Grade Level: 4th

Instructional Mode: Large Group

Team/ Group Size: 4 students

Summary: This lesson helps student understand how exactly greenhouses work. The students will understand how the atmosphere in the jar, may be a much smaller scale, however, acts in the same way as the atmosphere of the earth.

Learning Objectives:

2004 Worcester Public Schools Benchmarks for 4th Grade

<u>Skills of Inquiry</u>

Students Will…

04.SC.IS.01	Ask questions and make predictions that can be tested.
04.SC.IS.03	Keep accurate records while conducting simple investigations or experiments.
04.SC.IS.06	Record data and communicate findings with others using graphs, charts, maps, models, and oral and written reports.

<u>Physical Science</u>

Students Will…

04.SC.PS.02	Identify the basic forms of energy (light, sound heat, electrical, and magnetic). Recognize that energy is the ability to cause motion or create change.
04.SC.PS.03	Give examples of how energy an be transferred from one form to another.

<u>Technology/Engineering</u>

Students Will…

04.SC.TE.01	Identify materials used to accomplish a design task based on specific property.
04.SC.TE.04	Identify a problem that reflects the need for shelter, storage or convenience.

Essential Questions:

1. How does a greenhouse work?
2. How is a greenhouse like the Earth's atmosphere?
3. Why does the sun heat up an object?

Introduction/Motivation: Attached Information

Procedure:

1. Distribute materials to groups of 4 or less.
2. Place both thermometers in the sun about 3-6 apart and wait about 3 minutes for the temperature to stabilize.
3. Record the temperatures of both thermometer #1 and thermometer #2 in the engineering notebook.
4. Place a jar over thermometer #1 (numbering is arbitrary, it's just used so all students have consistent result) and make sure that the jar does not cast a shadow on thermometer #2.
5. Record both of the temperatures in the engineering notebooks every minute for the next ten minutes. (there should be 11 measurements in total)
6. Graph the results of the measurements in engineering notebook.

Materials:

- Small thermometers (2 per group)
- A jar or any see-through covering, large enough to have a small thermometer inside. (1 per group)

Vocabulary with Definitions:

Thermometer- A device used to measure the temperature of a surrounding area or object.

Greenhouse- A building used to grow plants in cold climates because if its ability trap and transform light energy into heat energy.

Greenhouse Effect- How the earth acts like a greenhouse and creates a livable environment for all of earth's plants and animals.

Atmosphere- The area around an object.

Assessment/Evaluation of Students: Graded on participation, final graph and effort.

Troubleshooting Tips:

-Make sure the jar for thermometer #1 doesn't shade thermometer #2
-If thermometers with stands are not available, have the student's think of creative ways to keep the thermometer vertical.
-Make sure that the jar can be read through from the outside. Lifting the jar to read temperature will give bad results.

Safety Issues:

Use alcohol or electronic thermometers rather than mercury thermometers

Source:

http://sln.fi.edu/tfi/activity/earth/earth-5.html

“The air over the exposed thermometer is constantly changing, and as it gets warm it is replaced by cooler air. Because the air in the jar cannot circulate to the rest of the room, this air stays in the sunlight and gets warmer and warmer. A similar trapping of heat happens in the Earth's atmosphere. Sunlight passes through the atmosphere and warms the Earth's surface. The heat radiating from the surface is trapped by greenhouse gasses. Without an atmosphere, the Earth's temperature would average about 0F. This warming due to heat-trapping gasses is called the "Greenhouse Effect." Both the atmosphere and the jar allow light to enter, but then trap that energy when it is converted to heat. They work differently, however, because the jar keeps in the heated air, while the greenhouse gasses absorb radiative heat.”

-http://sln.fi.edu/tfi/activity/earth/earth-5.html

“Have you ever seen a greenhouse? Most greenhouses look like a small glass house. Greenhouses are used to grow plants, especially in the winter. Greenhouses work by trapping heat from the sun. The glass panels of the greenhouse let in light but keep heat from escaping. This causes the greenhouse to heat up, much like the inside of a car parked in sunlight, and keeps the plants warm enough to live in the winter.

The Earth’s atmosphere is all around us. It is the air that we breathe. Greenhouse gases in the atmosphere behave much like the glass panes in a greenhouse. Sunlight enters the Earth's atmosphere, passing through the blanket of greenhouse gases. As it reaches the Earth's surface, land, water, and biosphere absorb the sunlight’s energy. Once absorbed, this energy is sent back into the atmosphere. Some of the energy passes back into space, but much of it remains trapped in the atmosphere by the greenhouse gases, causing our world to heat up.

The greenhouse effect is important. Without the greenhouse effect, the Earth would not be warm enough for humans to live. But if the greenhouse effect becomes stronger, it could make the Earth warmer than usual. Even a little extra warming may cause problems for humans, plants, and animals.”

-**www.epa.gov/globalwarming/ kids/greenhouse.html**

Figure 25: Greenhouse Example

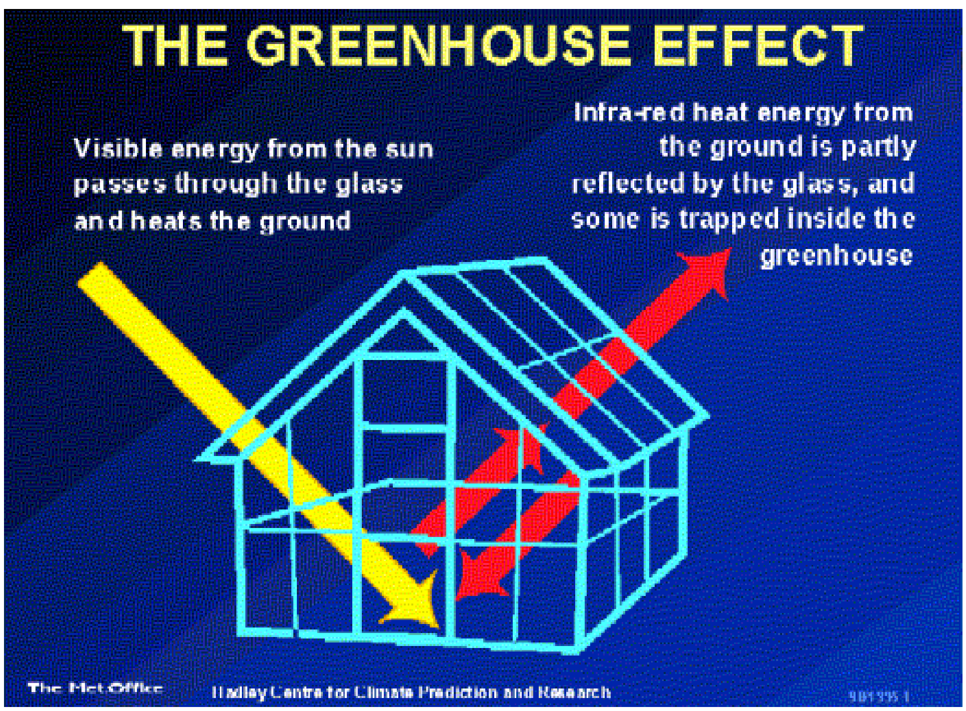


Figure 26: Greenhouse Effect

www.defra.gov.uk/environment/_climatechange/01.html
www.bluecloud.org/

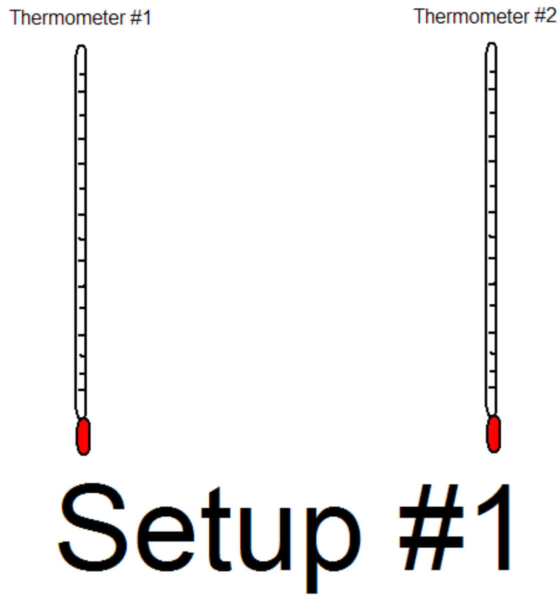


Figure 27: Thermometer Setup

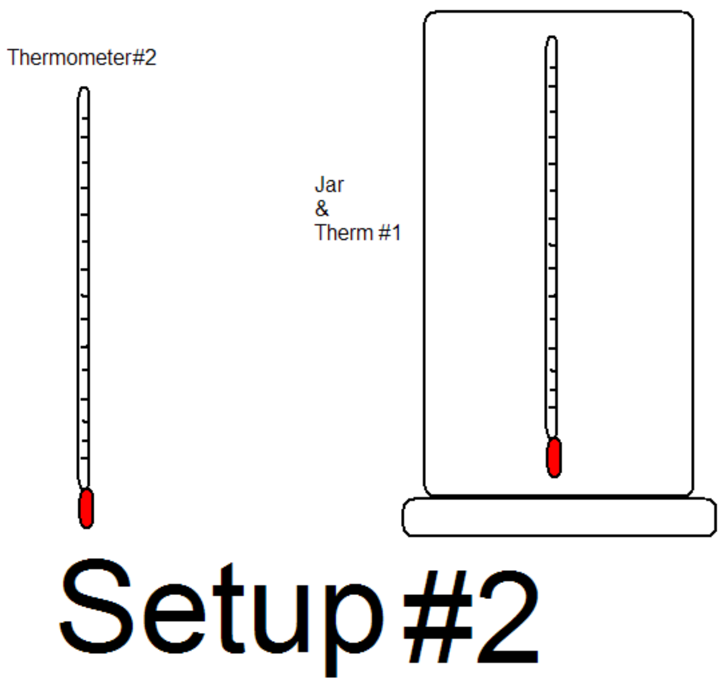


Figure 28: Thermometer Setup 2

IV
R

Lesson Title: Life Cycle and Inherited Traits

Grade Level: 4th

Instructional Mode: Small Groups

Team/ Group Size: 2

Summary: Groups of students will look at two different pictures of frogs and guess what types of offspring could possibly be generated by the two animals. Each group will be given two different characteristics to analyze.

Learning Objectives:

2004 Worcester Public Schools Benchmarks for 4th Grade

<u>Skills of Inquiry</u>

Students Will…

04.SC.IS.01	Ask questions and make predictions that can be tested.
04.SC.IS.02	Select and use appropriate tools and technology (e.g., calculators, computers, balances, scales, meter sticks, graduated cylinders) in order to extend observations.
04.SC.IS.03	Keep accurate records while conducting simple investigations or experiments.
04.SC.IS.05	Recognize simple patterns in data and use data to create a reasonable explanation for the results of an investigation or experiment.
04.SC.IS.06	Record data and communicate findings to others using graphs, charts, maps, models, and oral and written reports.

<u>Technology & Engineering</u>

Students Will…

04.SC.TE.01	Identify materials used to accomplish a design task based on specific properties
04.SC.TE.04	Identify a problem that reflects the need for shelter, storage or convenience.
04.SC.TE.05	Describe the different ways in which a problem can be represented (e.g., sketches, diagrams, graphic organizers and lists).
04.SC.TE.06	Identify relevant design features (e.g., size, shape, weight) for building a prototype of a solution to a given problem.

Life Science

Students Will…

04.SC.LS.03	Differentiate between observed characteristics of plants and animals that are fully inherited (e.g., color of flower, shape of leaves, color of eyes, number of appendages) and characteristics that are affected by climate or environment (e.g., browning of leaves due to too much sun, biorhythms).
04.SC.LS.05	Give examples of how inherited characteristics may change over time as adaptations to change in the environment that enable organisms to survive(e.g., shape of beak or feet, placement of eyes on head, length of neck, shape of teeth, color).
04.SC.LS.06	Compare and contrast the physical characteristics of plants or animals from widely different environments (desert vs. tropical plants; aquatic vs. terrestrial animals
04.SC.LS.07	Give examples of how changes in the environment (drought, cold) have caused some plants and animals to die or move to new locations (migration).
04.SC.LS.08	Investigate how invasive species out-compete native plants (e.g., phragmites and purple loose-strife). Discuss how some native plants die as a result.

Essential Questions:

What traits are possible based on parents of offspring?

Introduction/Motivation:

Explain to the students that there are different stages to the life cycle for frogs. Explain each individual stage.

Stages of the life cycle:

Egg - Frogs and Toads tend to lay many eggs because there are many hazards between fertilization and becoming a full grown frog. Those eggs that die tend to turn white or opaque. Life starts right as the central yolk splits in two. It then divides into four, then eight, etc.- until it looks a bit like a raspberry inside a jelly cup. Soon, the embryo starts to look more and more like a tadpole, getting longer and moving about in it's egg. Usually, about 6-21 days (on average) after being fertilized, the egg will hatch. Most eggs are found in calm or static waters, to prevent getting too rumbled about in infancy. Some frogs, like the Coast foam-nest tree frog, actually mate in tree branches overlooking static bonds and streams. Their egg masses form large cocoon-like foamy masses. The foam sometimes cakes dry in the sun, protecting the inside moisture. When rain comes along, after development of 7 to 9 days, the foam drips down dropping the tiny tadpoles into the river or pond below.

Tadpole - Shortly after hatching, the tadpole still feeds on the remaining yolk, which is actually in its gut. The tadpole at this point consists of poorly developed gills, a mouth, and a tail. It's really fragile at this point. They usually will stick themselves to floating weeds or grasses in the water using little sticky organs between it’s mouth and belly area. Then, 7 to 10 days after the tadpole has hatched, it will begin to swim around and feed on algae. After about 4 weeks, the gills start getting grown over by skin, until they eventually disappear. The tadpoles get teeny tiny teeth which help them grate food turning it into soupy oxygenated particles. They have long coiled guts that help them digest as much nutrients from their meager diets as possible. By the fourth week, tadpoles can actually be fairly social creatures. Some even interact and school like fish.

Tadpole with legs - After about 6 to 9 weeks, little tiny legs start to sprout. The head becomes more distinct and the body elongates. By now the diet may grow to include larger items like dead insects and even plants. The arms will begin to bulge where they will eventually pop out, elbow first. After about 9 weeks, the tadpole looks more like a teeny frog with a really long tail. It is now well on it's way to being almost full grown.

Young Frog or Froglet - By 12 weeks, the tadpole has only a teeny tail stub and looks like a miniature version of the adult frog. Soon, it will leave the water, only to return again to lay more eggs and start the process all over again.

Adult Frog - By between 12 to 16 weeks, depending on water and food supply, the frog has completed the full growth cycle. Some frogs that live in higher altitudes or in colder places might take a whole winter to go through the tadpole stage...others may have unique development stages that vary from your "traditional" tadpole-in-the-water type life cycle. Now these frogs will start the whole process again...finding mates and creating new frogs.

Procedure:

1. Students will identify their two traits.
2. They will then place the characteristics on their worksheet and figure out the possibilities for four children on what characteristics will they inherit.
3. Students will then present their findings in front of the class.

Materials:

-Pencil (2 per group)
-Crayons (1 box per group)
-Markers (2 per group)

Vocabulary with Definitions:

Cycle- A chain of events or stages that circle back to the original event or stage.

Assessment/Evaluation of Students: Graded on drafts, participation and presentation.

Attachments: Handouts that each student will fill out and be graded on.

Troubleshooting Tips:

With the inherited traits sheet you need to put the same type of traits on the same side of the box, one in each column. For example, you put large warts and small warts on the same side. Does the same thing along the side, then figure out which two traits go in each box by just looking at the chart. Help them understand the exact traits that each animal has.

IV
S

Lesson Title: Structure of an Atom

Grade Level: 4th

Instructional Mode: Large Groups

Team/ Group Size: 4

Summary: Groups of students will be given information on the elements carbon and oxygen. Each group will build the elements out of colored cotton balls which will represent protons, neutrons, and electrons. After the groups are finished they will be given the option to try to make another element from the periodic table.

Learning Objectives:

2004 Worcester Public Schools Benchmarks for 4th Grade

Skills of Inquiry

Students Will…

04.SC.IS.01	Ask questions and make predictions that can be tested.
04.SC.IS.02	Select and use appropriate tools and technology (e.g., calculators, computers, balances, scales, meter sticks, graduated cylinders) in order to extend observations.
04.SC.IS.03	Keep accurate records while conducting simple investigations or experiments.
04.SC.IS.05	Recognize simple patterns in data and use data to create a reasonable explanation for the results of an investigation or experiment.
04.SC.IS.06	Record data and communicate findings to others using graphs, charts, maps, models, and oral and written reports.

Technology & Engineering

Students Will…

04.SC.TE.01	Identify materials used to accomplish a design task based on specific properties.
04.SC.TE.04	Identify a problem that reflects the need for shelter, storage or convenience.
04.SC.TE.05	Describe the different ways in which a problem can be represented (e.g., sketches, diagrams, graphic organizers and lists).
04.SC.TE.06	Identify relevant design features (e.g., size, shape, weight) for building a prototype of a solution to a given problem.

Physical Science

Students Will…

04.SC.PS.06	Identify and classify objects and materials that conduct electricity and objects and materials that are insulators of electricity.
04.SC.PS.07	Determine the electrical conductivity of a collection of materials by testing the materials with a simple battery/ bulb circuit.
04.SC.PS.08	Explain how electromagnets can be made, and give examples of how they can be used.
04.SC.PS.09	Describe and model the basic structure of the atom, e.g., carbon and oxygen.

Essential Questions:

What 3 things make up an element?
What is a proton?
What is a neutron?
What is an electron?

Introduction/Motivation:

Teachers will explain to the students that elements are made up of atoms. Atoms are made up of protons, neutrons, and electrons. The nucleuses of atoms are made up of protons and neutrons. Electrons orbit the nucleus of the atoms. Teachers must explain how there are equal parts of protons and neutrons in the nucleus of the atom. There are also equal parts of protons and electrons. The Atomic number of the atom is also equal to the amount of protons and electrons in the atom. Teachers must also explain how many electrons can be located on each electron shell.

Procedure:

1. Students will identify the element from the periodic table of elements.
2. They will draw the nucleus and the protons and neutrons located in it.
3. The students will then draw the orbit of the electrons around the nucleus and the electrons located on the orbits.
4. The students will place red cotton balls in place of the protons.
5. The students will place blue cotton balls in place of the neutrons.
6. The students will place yellow cotton balls in place of the electrons.

Materials:

-Pencil (1 per student)
-Crayons (1 box per group)
-Markers (1 per group)
-Red cotton balls (10 per group)
-Blue cotton balls (10 per group)
-Yellow cotton balls (10 per group)

Vocabulary with Definitions:

Atom- A unit of matter that is the smallest in an element.

Proton- A particle in an atom’s nucleus.

Neutron- A particle in an atomic nucleus that has a mass close to that of a proton, but is not present in hydrogen

Electron- A particle that orbits the nucleus.

Electron shell- A group of electrons orbiting the nucleus of an atom.

Assessment/Evaluation of Students: Graded on drafts, participation and presentation.

IV
T

Lesson Title: Metamorphosis

Grade Level: 4th

Instructional Mode: Large Group

Team/ Group Size: Individuals

Summary: Students will design a creature that goes through three stages of metamorphosis. Students will also design three different predators (simple ideas, nothing complicated) for each step in the creature's metamorphosis. The creature must have some sort of defense against the imaginary predator in each metamorphosis phase.

Learning Objectives:

2004 Worcester Public Schools Benchmarks for 4th Grade

Skills of Inquiry

Students Will…

04.SC.IS.01 Ask questions and make predictions that can be tested.

Technology/Engineering

Students Will…

04.SC.TE.06 Identify relevant design features for building a prototype of a solution to a given problem.

Life Science

Students Will…

04.SC.LS.01 Describe the major that characterize the life cycle of the frog and butterfly as they grow through metamorphosis.

04.SC.LS.06 Compare and contrast the physical characteristics of plants of animals from widely different environments. Explore how each is adapted to its environment

Introduction/Motivation:

Talk to the students about Metamorphosis, and several examples of creatures that undergo it.

Procedure:

1. Pass out lined.
2. Have student write a sentence or two about the creature, and imaginary predator that they would like to design.
3. Pass out the worksheets attached.
4. Have them follow the directions on the page.

Materials:

- Lined Paper (2 pages per student)

Vocabulary with Definitions:

Metamorphosis- The changes in the form and habits of an organism during development stages after birth.

Assessment/Evaluation of Students:

Students are graded on participation, effort and level of creativity.

Name: Date:

Draw a picture of your creature in its first stage of Metamorphosis.

Draw a picture of your creature interacting with a predator in its first stage of Metamorphosis.

Name: Date:

Draw a picture of your creature in its second stage of Metamorphosis.

Draw a picture of your creature interacting with a predator in its second stage of Metamorphosis.

Name: Date:

Draw a picture of your creature in its third stage of Metamorphosis.

Draw a picture of your creature interacting with a predator in its third stage of Metamorphosis.

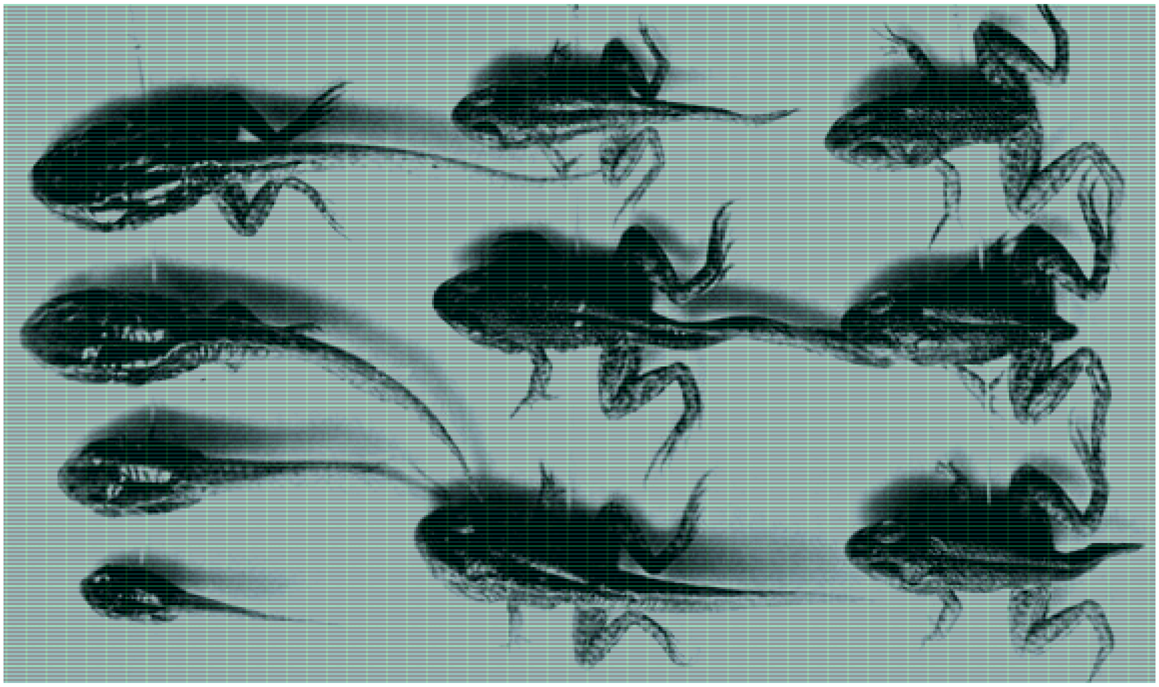


Figure 29: Metamorphosis of the Frog

http://www.calarts.edu/~shockley/frogchart.gif

Figure 30: Metamorphosis of the Butterfly

http://www.tiscali.co.uk/reference/encyclopaedia/hutchinson/images/0008n004.jpg

V

A
Rubber Band Banjo
Evaluation and Corrections

Lesson Plan Assessment Form

PIEE Student John Paietti Date 3/30/05

School Elm Park Grade Level 4 Name of Lesson Rubber Band Banjo

Date of Implemented Lesson 12/04 Name of Evaluator Lori Degnan

WPS Benchmarks Implemented 04. SC. PS. 01 / MSTECF - 4.3.11

Assessment Key:
0=Strongly Disagree 1=Disagree 2=Agree 3=Strongly Agree
Place an X in the designated boxes with optional comments.

Do you agree that..?	0	1	2	3	NA	Comments
The lesson plan was appropriate for the grade level?				✓		
The lesson plan encouraged children's original ideas?		✓				Originality was not a component of this lesson.
The students understood the information that was instructed?				✓		
The materials used were appropriate? (e.g. cost, reusability, easy to use)			✓			Rubber bands could've been more varied sizes.
The lesson plan followed the WPS Benchmarks?				✓		
The PIEE student's parcticipation/instruction was useful?				✓		
The overall quality of the lesson plan was excellent?			✓			See Rubber Band Comment Above

What was the strongest component of this lesson? Please give an example of why this quality was important.

This lesson was a simple and inexpensive way to teach pitch and loudness and the students had alot of fun with it.

What was the weakest component of this lesson and what would you change to make it better so that it can be used in the future?

Rubber bands were not varied enough. Also, if rubber bands can be separated ahead of time and be passe out by the teacher as a group of 8, it would be helpful, more organized and less chaotic.

Any additional comments?

No additional comments.

Lesson Plan Assessment Form Grading Rubric

Name:_Johnny Parretti________________ **Date:**_04-05-05_________

Instructions:
Take the total number of points earned and divide it by the total number of possible points minus the possible points from the NA boxes. Then multiply that number by 100.

Example:
Total possible points: 24
Number of NA's: 2
24-2=22
Total points earned: 17
17/22 X 100= about 77 %

You received _77________ % on your evaluation

Do you agree with your score and why do you feel this way?

I agree with my score. I sat down with the teacher and made sure that everything that she felt about the lesson and I felt about it went into her critique. I pushed to have as much feedback as possible so as to improve the lesson plan to the best of my ability.

What changes could you make to better this lesson and how would those changes make an impact on the outcome?

Based on the comments, I will go back and revise the lesson to account for more types of rubber bands. I will also add a troubleshooting section for teachers to read. I feel this will adequately improve the quality of the lesson plan.

Learning from your experience with this lesson, what will you do in your future lessons to better their quality?

I will be more descriptive and always include a troubleshooting section for the teachers.

Lesson Title: Rubber Band Banjo

Grade Level: 4th

Lesson Time: 50 minutes

Instructional Mode: Entire Class

Summary: The students will learn how to make a basic musical instrument and how to modify it to get different loudness and pitches.

Learning Objectives:

2004 Worcester Public Schools Benchmarks for the 4th Grade

Physical science

Students will...

04.SC.PS.01: Design and construct a simple sound-producing device to predict, demonstrate, and describe the properties of loudness and pitch of sound.

MSTECF Standards

4.3.11: Recognize that sound is produced by vibrating objects

Essential Questions:

How can I modify the loudness and pitch of my rubber band banjo?

Procedure:

3. Review sound and pitch quickly (10 minutes)
4. Split the class into groups of two students: (40 minutes)
    a. Hand out materials to each group
    b. Write the numbers 1-8 on the inside of the lid. Use a ruler to space them evenly across the whole lid. (See attachment: Banjo)
    c. Put three thick rubber bands around the lid over the numbers 1 through 3.
    d. Put three medium rubber bands around the lid over numbers 4 through 6.
    e. Put two thin rubber bands around the other portion of the lid over the numbers 7 through 8.
    f. Have the students answer the following questions in their science notebook:
        vii. Pluck one of the rubber bands. How can you make a soft sound? Louder sound?
        viii. Which bands (thick, medium or thin) make higher sounds? (the highness and lowness of a sound is pitch)
        ix. Press down a rubber band halfway across the lid. Pluck the piece of the rubber band closest to you. What happens to the pitch when you shorten the rubber band?

x. How does tightening the band have an affect on pitch? Loosening the band? (you can do this by pulling the band near the edge of the cover.
xi. Try to make an 8-note scale. (Do-Re-Mi-Fa-So-La-Ti-Do) (pluck lightly so the strings stay tuned)
xii. Once tuned, have them play 1-1-1-2-3 3-2-3-4-5 8-8-8 5-5-5 3-3-3 1-1-1 5-4-3-2-1. See if they can figure out what song it is. (Row-Row-Row your boat)

Materials List (per group):

-Shoe box lid (or the equivalent)
-3 thick rubber bands
-3 medium rubber bands
-4 thin rubber bands

Vocabulary with Definition:

Frequency– How fast something (like a sound producing rubber band) vibrates. The faster the vibration, the higher the frequency.

8-note Scale– The basic notes of Do-Re-Mi-Fa-So-La-Ti-Do

**All other vocabulary and definitions should have been thoroughly covered in the last two lessons.*

Assessment/Evaluation of Students:

Grade based on the student's effort, the student's grasp of the concepts or frequency and pitch and group-work ability.

Attachments: Stringed Instruments, Rubber Band Banjo Background, Banjo

Key Words: Sound, Pitch, Loudness, 8-note scale

Troubleshooting Tips:

Try the project for yourself first, make sure you have adequate rubber bands. It is up to the teacher whether to give the children the 8 rubber bands or have them decide which ones to use on their own.

Revisions:

The number and types of the rubber bands were changed per order of the teacher and a troubleshooting section was added.

Sources: Science in Elementary Education 7th Edition, Peter C. Gega, 1994

Rubber Band Banjo Background

Preparation and Background:

The tightness, thickness, and length of a rubber band (or string) all affect its pitch. Sounds are higher with taut, thin, short strings; they are lower with looser, thicker, or longer strings on any stringed instrument. The tension of each rubber band may be adjusted by pulling up or down at the side of the lid. Friction between the band and the lid hold the band in place for a while. However, the band will need to be strummed or plucked gently. A sturdy lid is preferable to a flimsy one that bows in the middle.

Generalization:

The length, tension and thickness all affect the pitch of the vibrating string/rubber band.

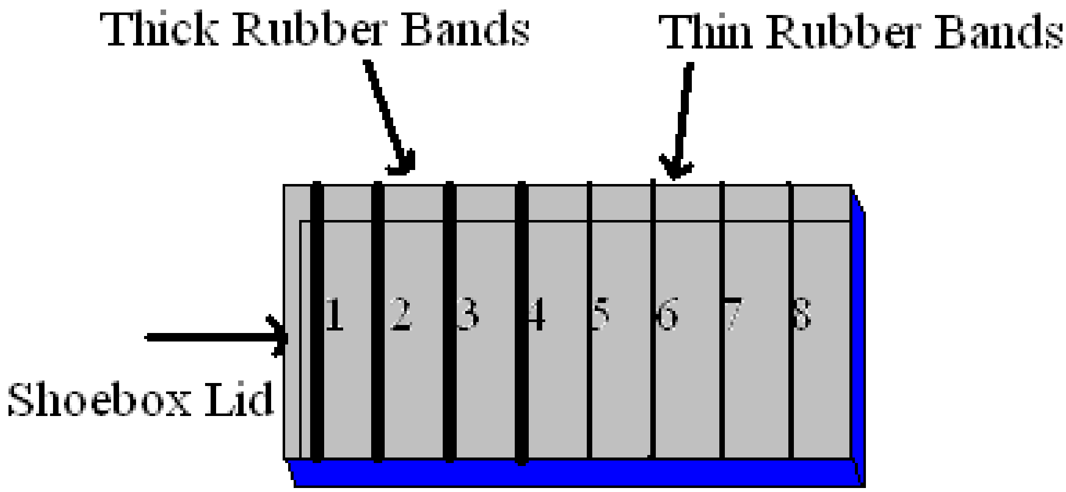
Comments:

Parts 5 and 6 can be somewhat difficult and not all students may be able to understand/complete them. These are more like extra credit problems for groups that excel in sound and waves.

Sources –

Science in Elementary Education 7th Edition, Peter C. Gega, 1994

Banjo



Sources –

Science in Elementary Education 7th Edition, Peter C. Gega, 1994

Stringed Instruments

***Teacher's note*:**

Please do not teach this word for word. Read and understand it yourself and only teach what you feel is necessary to get the lesson and vocabulary across to your students.

In a stringed instrument, pitch depends on the length, tightness, and thickness of the strings. Shortening a string causes faster vibrations, raising pitch. Lengthening it has an opposite effect. Tightening a string also increases pitch, whereas lessening tension decreases it. A thick string vibrates more slowly than a thin one, and so produces a lower sound.

Why do different instruments- a violin and a cello, for instance- play a note at the same pitch yet sound different? This is because of the *quality* of tone (timbre) produced by these instruments. Most vibrations include more than just simple, back-and-forth movements along a strings entire length. Although there is a fundamental vibration that covers the basic pitch, other strings vibrate at faster frequencies. The combinations of vibrations are different with each string and with various stringed instruments. Together they produce tones of distinctly recognizable quality.

Sources –

Science in Elementary Education 7th Edition, Peter C. Gega, 1994

V

B

Environmental Creations Evaluation and Corrections

Lesson Plan Assessment Form

PIEE Student Paul Ragaglia Date 3/30/05

School Elm Park Grade Level 4 Name of Lesson Environmental Creations

Date of Implemented Lesson 3/30 + 3/31 Name of Evaluator Lori Degnan

WPS Benchmarks Implemented IS. 01-06 / LS. 03, 05,-08 / TE. 01, 04-06

Assessment Key:
0=Strongly Disagree 1=Disagree 2=Agree 3=Strongly Agree
Place an X in the designated boxes with optional comments.

Do you agree that..?	0	1	2	3	NA	Comments
The lesson plan was appropriate for the grade level?				✓		
The lesson plan encouraged children's original ideas?				✓		
The students understood the information that was instructed?				✓		
The materials used were appropriate? (e.g. cost, reusability, easy to use)				✓		
The lesson plan followed the WPS Benchmarks?				✓		
The PIEE student's parcticipation/instruction was useful?				✓		
The overall quality of the lesson plan was excellent?				✓		

What was the strongest component of this lesson? Please give an example of why this quality was important.

I liked the fact that the kids could use their imaginations and freely come up with whatever they wanted to to complete this activity. So much of education today is scripted and doesn't leave much to the imagination.

What was the weakest component of this lesson and what would you change to make it better so that it can be used in the future?

None

Any additional comments?

No additional comments needed.

Lesson Plan Assessment Form Grading Rubric

Name:_Paul Ragaglia_______________ **Date:_4-5-05___________**

Instructions:
Take the total number of points earned and divide it by the total number of possible points minus the possible points from the NA boxes. Then multiply that number by 100.

Example:
Total possible points: 24
Number of NA's: 2
24-2=22
Total points earned: 17
17/22 X 100= about 77 %

You received 100_______ % on your evaluation

Do you agree with your score and why do you feel this way?

I felt my lesson went very well and I am happy with the score. I, like the teacher, felt no revisions were necessary for the lesson plan.

What changes could you make to better this lesson and how would those changes make an impact on the outcome?

N/A

Learning from your experience with this lesson, what will you do in your future lessons to better their quality?

Make sure they are like this one.

V
C
Simple Forces
Evaluation and Corrections

Lesson Plan Assessment Form

PIEE Student Andrea Flynn Date 3-28-05

School ElmPark Grade Level 4 Name of Lesson Simple Machine

Date of Implemented Lesson March Name of Evaluator Jodi Towne

WPS Benchmarks Implemented____________________

Assessment Key:
0=Strongly Disagree 1=Disagree 2=Agree 3=Strongly Agree
Place an X in the designated boxes with optional comments.

Do you agree that..?	0	1	2	3	NA	Comments
The lesson plan was appropriate for the grade level?				X		
The lesson plan encouraged children's original ideas?				X		
The students understood the information that was instructed?				X		
The materials used were appropriate? (e.g. cost, reusability, easy to use)				X		
The lesson plan followed the WPS Benchmarks?				X		
The PIEE student's participation/instruction was useful?				X		
The overall quality of the lesson plan was excellent?				X		

Lesson Plan Assessment Form Grading Rubric

Name:_Andrea Flynn_______________ **Date:_4-5-05___________**

Instructions:
Take the total number of points earned and divide it by the total number of possible points minus the possible points from the NA boxes. Then multiply that number by 100.

Example:
Total possible points: 24
Number of NA's: 2
24-2=22
Total points earned: 17
17/22 X 100= about 77 %

You received 100_______ % on your evaluation

Do you agree with your score and why do you feel this way?

I feel that the lesson plan went very well.

What changes could you make to better this lesson and how would those changes make an impact on the outcome?

I don't feel any changes are necessary.

Learning from your experience with this lesson, what will you do in your future lessons to better their quality?

Try to make the hands on activities fun and educational.

V
D
Adaptation
Evaluation and Corrections

Lesson Plan Assessment Form

PIEE Student Rick Date 4/18/05

School Midland Grade Level 4 Name of Lesson Adaptation GAME

Date of Implemented Lesson 4/8/05 Name of Evaluator Sue

WPS Benchmarks Implemented

Assessment Key:
0=Strongly Disagree 1=Disagree 2=Agree 3=Strongly Agree
Place an X in the designated boxes with optional comments.

Do you agree that..?	0	1	2	3	NA	Comments
The lesson plan was appropriate for the grade level?				✓		
The lesson plan encouraged children's original ideas?				✓		
The students understood the information that was instructed?				✓		
The materials used were appropriate? (e.g. cost, reusability, easy to use)				✓		
The lesson plan followed the WPS Benchmarks?				✓		
The PIEE student's parcticipation/instruction was useful?				✓		
The overall quality of the lesson plan was excellent?				✓		

What was the strongest component of this lesson? Please give an example of why this quality was important.

The kids were very engaged and enjoyed drawing. This is important because the students participated and wanted to learn.

What was the weakest component of this lesson and what would you change to make it better so that it can be used in the future?

A couple of words were unfamiliar to the students.

Change the words to age appropriate.

Any additional comments?

∅

V
E
Metamorphosis
Evaluation and Corrections

Lesson Plan Assessment Form

PIEE Student Daniel Barth   Date 04/25/05

School Midlands St. Grade Level 4   Name of Lesson Metamorphosis

Date of Implemented Lesson 04/06/05   Name of Evaluator Phillip Carlson

WPS Benchmarks Implemented 04.SC.18.01, 04.SC.TE.06, 04.SC.LS.01 + 06

Assessment Key:
0=Strongly Disagree 1=Disagree 2=Agree 3=Strongly Agree
Place an X in the designated boxes with optional comments.

Do you agree that..?	0	1	2	3	NA	Comments
The lesson plan was appropriate for the grade level?				✓		
The lesson plan encouraged children's original ideas?				✓		
The students understood the information that was instructed?				✓		
The materials used were appropriate? (e.g. cost, reusability, easy to use)				✓		
The lesson plan followed the WPS Benchmarks?				✓		
The PIEE student's parcticipation/instruction was useful?				✓		
The overall quality of the lesson plan was excellent?				✓		

What was the strongest component of this lesson? Please give an example of why this quality was important. The strongest component of this lesson was the students' ability to be as creative as they wish. Many students had a hard time thinking of what they wanted to draw without me or Daniel giving them exact guidance. When they realized they had full creative freedom, they came up with many unique and interesting creatures.

What was the weakest component of this lesson and what would you change to make it better so that it can be used in the future?

Writing a paragraph about the creature required too much concentration for the students. In the future, have it shortened to one or two sentences.

Any additional comments?

Ø

VI
Timeline

A Term:

9/23/04	Draft 1 of Literature Review # 1
9/30/04	Draft of PowerPoint Draft 2 of Literature Review # 1 Draft 1 of Literature Review # 2 Draft 1 of Lesson # 1 Table of Contents Rough Skeleton Outline of Project
10/7/04	Draft 3 of Literature Review # 1 Draft 2 of Literature Review # 2 Draft 2 of Lesson # 1 Draft 1 of Lesson # 2
10/14/04	Proposal Bibliography and Citations Finalize PowerPoint Presentation
10/25/04	IQP All Hands Meeting PowerPoint Presentation

B Term:

10/28/04	Revise Lesson Plans as Necessary
11/04/04	Revise Lesson Plans as Necessary
11/11/04	Revise Lesson Plans as Necessary
11/15/04	Implement Lesson 1
11/18/04	Revise Lesson Plans as Necessary

C Term:

1/30/05	Implement Lesson 2
3/01/05	Teacher Assessment

D Term:

3/17/05	Revise Lesson Plans as Necessary
3/24/05	Revise Lesson Plans as Necessary
3/31/05	Revise Lesson Plans as Necessary
4/07/05	Revise Lesson Plans as Necessary
4/15/05	Lesson Plans Final Revision
4/30/05	Final IQP Project Due

VII
Methodology

Writing lesson plans was not just looking on the internet or looking through a book, but mostly inspiration from many small factors. The internet has its benefits and helps with some troubleshooting, but most of the ideas come from imagination. The imagination of a student who actually participates in the activities is the same imagination which creates these activities. The fourth grade IQP team created easy-to-understand, fun and creative lessons to improve the curriculum of Midland Street School and Elm Park Community School.

The team was informed of the areas of study which needed help with new lesson plans. The group immediately came up with some ideas that would be very educational yet very fun as well. With the aid of the two graduate fellows, the team used these basic ideas to form lessons. Ideas from previous experience, as well as inspiration from previous lesson plans meshed well with the development of new lessons.

After gathering ideas, members of the IQP team swapped comments and suggestions to make the lessons better. Next, the IQP students used a template in order to construct the lesson in a certain format. The lesson was then submitted to the graduate fellows for editing. After editing, the lesson plan was returned to the IQP student to make corrections. This editing process happened several times until a final, complete draft was formed.

Following the completion of the lesson plan, scheduling the lesson was the next step. A schedule was made by looking at the class curriculum calendar for the coming school year and estimating when the IQP student's lesson could be implemented. This was then discussed between the graduate fellows and the teacher of the fourth grade for specific dates. The lessons were not just approved by the graduate fellow, but the teachers as well. The only thing there was left to do was to implement the lesson plans. Once the lesson plan had been implemented, the teacher of the class then filled out a lesson plan evaluation form and returned to the graduate fellow. The information of the lesson assessment form is for future use and can be seen in Section X Appendix D.

Looking back from the start of creating the lesson plans to the end of editing, many steps and procedures were followed in order to have effectiveness with the implementation of these lesson plans. Also, with the addition of lesson assessment form, the comments could be used for updating current lesson plans and for developing future lesson plans.

VIII
Observations

During our session in the classrooms, many things became apparent about the types of students that we were working with. While working with both the Elm Park and Midland Elementary Schools it became obvious that the students at each school were very different. The first difference that seemed very obvious to all of was the demographics of the two schools. Elm Park Elementary School is located in a part of Worcester that does not contain some of the more child developing features that most parents would like their children to grow up in. The surrounding area of Elm Park is densely populated with houses that are not in the best of condition. It is also an area that does not look like it can foster the types of activities that can be good for young children. As for Midland Elementary School it is located in a very different type of area. The surrounding area of Midland School is very spread out and organized in a very community friendly manner. Most houses surrounding Midland contain both front and back yards and seem to be bolster activities that are good for young minds. These demographics are just the first and most obvious differences between the two schools.

Another observation that was noticed by the participants of the program was of the teachers and their teaching styles. The teachers from Elm Park seem younger and newer to teaching compared to the teachers from Midland. The Elm Park teachers handled situations different than the Midland teachers in the sense of punishments. Elm Park teachers do not punish their student in the same manner that Midland teachers do. Midland teachers handle punishment seriously; they understand that they have to convey the rights and wrongs associated within a classroom. Elm Park teachers handled punishments more along the lines of something that is needed to be more severe but can not do it because they would be punishing the rest of the class as well. Midland teachers also seem more weathered to the types of situations that arise in the classroom. They always seem prepared and ready for the classroom; there never seems a moment where they are confused by lesson plans or by information that needs to be presented. As for some Elm Park teachers they often have difficulties grasping certain lesson plans and often change lesson plans to make them simpler for their students. The other noticeable difference between the two schools is the students.

The students at Elm Park were very misbehaved and seemed to lack the maturity of students at Midland school. Many of the students felt the overwhelming need to be the center of attention all the time and thus cause distractions to the other students in the classroom. With all of the distraction in the classroom it is difficult for teachers to keep order, but even with the poor attitude of Elm Park students the teachers should be able to control the classroom. As for the students from Midland Elementary they were always excited about learning, they strived to do well and challenge each other to do better. The students at Midland were also well behaved and could work by themselves without getting off topic or sidetracked on other areas of study. The differences seem large when looking at the amount each student learns and can reproduce. Elm Park students do not seem as prepared for higher grades as the Midland students. From all of the observations it seemed that Elm Park is not held at as high of a standard as Midland school.

With such different standards and expectations of each school district there are ways to tailor lesson plans to bolster students knowledge. One way to help students that struggle with reading and writing is to create lesson plans that contain more hands on activities that will keep students active. It is better to get students to understand a lesson through hands on activities then having students become uninterested and completely ignores a lesson. As for districts with students that are more comfortable with reading and writing, by adding an extra branch off lesson for students that excel in certain aspects of a lesson, they can get as much information as possible out of a lesson. These are just general guidelines to help improve lessons for different school districts.

IX
Conclusion

The Partnerships Implementing Engineering Education Project has been an exciting project that has brought new experiences to those involved. The students began attacking problems in a much more structured way as the year progressed. This improvement can be attributed to the implementation of the engineering design process in each lesson, which provided the students with a structured method of solving a problem.

This improvement differed from classroom to classroom. The question of why these differences exist has been discussed in the observations section. The team has drawn the conclusion that they cannot judge the overall effect of the classroom environment on students, but they do conclude that the IQP students at Midland Street Elementary School had an easier time implementing the lessons and the students show a more notable improvement over the progress of the year. The IQP students at Elm Park Elementary School expressed that their lessons were not as easy to implement and that the students did not absorb the concepts as well. From these differences the IQP team has concluded that the environment of a classroom has an impact on the successful implementation of engineering in the general science curriculum.

X
Bibliography

1. Boyer, E. (1988) Simpson's Contemporary Quotations, compiled by James B. Simpson. Copyright © 1988 by James B. Simpson. Published by the Houghton Mifflin Company.
2. Camp Reach (2003) Annual Report
3. The City of Worcester, Massachusetts (2003), City of Worcester, Massachusetts. Retrieved September 21, 2004 from the World Wide Web: http://www.ci.worcester.ma.us/
4. The Commonwealth of Massachusetts Department of Education, (2001), Science and Technology/Engineering Curriculum Framework
5. Girls in Engineering, Math and Science (2004) WPI GEMS Webpage, Retrieved September, 2004 from the World Wide Web: http://www.wpi.edu/Admin/Diversity/Girls/Gems/
6. Massachusetts Department of Education (2004), Directory Profiles, Massachusetts Department of Education. Retrieved September 28, 2004 from the World Wide Web: http://profiles.doe.mass.edu/home.asp?mode=o&ot=5&o=1906
7. Massachusetts Department of Education, State Government, (2004)
8. Miller, J. (September 17, 2004) E-Mail to the Author, "Midland St. after school--volunteer needed, RSVP."

9. Darby, Michael R. (1996) Reducing Poverty in America. London: Sage Publications.

10. National Science Foundation (2004), Funded Programs, Retrieved September, 2004 from the World Wide Web http://www.ehr.nsf.gov/gpra/fypgmlist.asp?fy=2003&pgm=7179&name=GK-12

11. Nicoletti, D. (2002), K-6 Gets a Piece of the PIEE: Projects Implementing Engineering Education, Retrieved September 24, 2004 from the World Wide Web http://www.wpi.edu/Academics/PIEE/Publications/nsfproposal.pdf

12. North Dakota State University (2004), NDSU Extension Service

13. Public Broadcasting System (2000-2001), Building Big, Retrieved September 30, 2004 from the World Wide Web: http://www.pbs.org/wgbh/buildingbig/index.html

14. Slotnick, N., (July 16, 2003) Shrewsbury Online News Website, Retrieved September, 2004 from the World Wide Web: http://www.townonline.com/shrewsbury/news/local_regional/art_science071620003.htm

15. Sontgerath, S., Diversity and Women's Programs Coordinator, (October 4, 2004)

16. Tipton, Debbie (2002), by PageWise Inc.

17. Webster's Dictionary (2004)

18. Worcester Public Schools (2004), Worcester Public Schools Home page, Retrieved September 21, 2004 from the World Wide Web: http://www.wpsweb.com/

19. Worcester Public Schools (2004), Worcester Public Schools Home page, Retrieved September 12, 2004 from the World Wide Web: http://www.wpsweb.com/science/wpscur.htm#mission_statement

20. Wikipedia (2000), Worcester, Massachusetts, Retrieved November, 2004 from the World Wide Web http://www.fact-index.com/w/wo/worcester__massachusetts.html

21. Balisdell, Stephanie (2004)

Interview with Stephanie Blaisdell

October 26th, 2004

XI
A.
Benchmarks

SCIENCE AND TECHNOLOGY/ ENGINEERING

KINDERGARTEN

Science uses the natural ability and developmental qualities of the child to enable him/her to develop skills that will help him/ her understand the world. The students' natural curiosity will be directed through observation, collection and record keeping of the physical and biologic elements in their world around them to understand their functions and place in the environment.

SKILLS OF INQUIRY	
(Tools for learning and life-long learning.)	
	Students will…
	Ask questions about objects, organisms, and events in the environment.
0K.SC.IS.02	Tell about why and what would happen if?
0K.SC.IS.03	Make predictions based on observed patterns.
0K.SC.IS.04	Name and use simple equipment and tools (e.g., rulers, meter sticks, thermometers, hand lenses, and balances) to gather data and extend the senses.
0K.SC.IS.05	Record observations and data with pictures, numbers or written statements.
0K.SC.IS.06	Discuss observations with others.
EARTH/SPACE SCIENCE	
	Students will…
0K.SC.ES.01	Recognize that water, rocks, soil, and living organisms are found on the earth's surface.
0K.SC.ES.02	Understand that air is a mixture of gases that is all around us and that wind is moving air.
0K.SC.ES.03	Use a hand pump to inflate a basketball. Observe and discuss how and why the basketball gets larger as you add more air.
LIFE SCIENCE	
	Students will…
0K.SC.LS.01	Recognize that animals (including humans) and plants are living things that grow, reproduce and need food, air and water.
0K.SC.LS.02	Draw and record the growth of a plant grown from seeds with different light exposures (vary the duration and intensity of light exposure).
0K.SC.LS.03	Differentiate between living and nonliving things. Group both living and nonliving things according to the characteristics they share.
0K.SC.LS.04	Compare and contrast groups of animals (e.g., insects, birds, fish or mammals) and look at how animals in these groups are more similar to one another than to animals in other groups.
0K.SC.LS.05	Recognize that plants and animals have life cycles, and that life cycles vary for different living things.
0K.SC.LS.06	Using either live organisms or pictures/models, observe the changes in form during the life cycle of a butterfly or frog.
0K.SC.LS.07	Discuss the life cycle of a tree.
0K.SC.LS.08	Describe ways in which many plants and animals closely resemble their parents in observed appearance.
0K.SC.LS.09	Look at and discuss pictures of animals from the same species. Observe and discuss how they are alike and how they are different.
PHYSICAL SCIENCE	
	Students will…
0K.SC.PS.01	Sort objects by observable properties such as size, shape, color, weight, and texture.
0K.SC.PS.02	Manipulate, observe, compare, describe, and group objects found in the classroom, on the playground, and at home.
0K.SC.PS.03	Identify objects and materials as solid, liquid, or gas. Recognize that solids have a definite shape and that liquids and gases take the shape of their container.
0K.SC.PS.04	Using transparent containers of very different shapes (e.g., cylinder, cone, cube) pour water from one container into another. Observe and discuss the "changing shape" of the water.
0K.SC.PS.05	Categorize and classify a group of sorted objects according to properties of shape, size, and color.
0K.SC.PS.06	Use their senses (sight, hearing and touch) to identify, describe and compare objects.
0K.SC.PS.07	Observe objects using a hand lens as a simple tool.
TECHNOLOGY/ENGINEERING	
	Students will…
0K.SC.TE.01	Identify and describe the characteristics of natural materials (e.g., wood, cotton, fur, wool) and human-made materials (e.g., plastic, Styrofoam).
0K.SC.TE.02	Identify tools and simple machines used for a specific purpose, e.g., ramp, wheel, pulley, lever.

GRADE ONE

Science uses the natural ability and developmental qualities of the child to enable him/her to develop skills that will help him/ her understand the world. The students' natural curiosity will be directed through observation, collection and record keeping of the physical and biologic elements in their world around them to understand their functions and place in the environment.

SKILLS OF INQUIRY

(Tools for learning and life-long learning.)

	Students will…
01.SC.IS.01	Ask questions about objects, organisms, and events in the environment.
01.SC.IS.02	Tell about why and what would happen if?
01.SC.IS.03	Make predictions based on observed patterns.
01.SC.IS.04	Name and use simple equipment and tools (e.g., rulers, meter sticks, thermometers, hand lenses, and balances) to gather data and extend the senses.
01.SC.IS.05	Record observations and data with pictures, numbers or written statements.
01.SC.IS.06	Discuss observations with others.

EARTH/SPACE SCIENCE

	Students will…
01.SC.ES.01	Understand that air is a mixture of gases that is all around us and that wind is moving air.
01.SC.ES.02	Describe the weather changes from day to day and over the seasons.
01.SC.ES.03	Recognize that the sun supplies heat and light to the earth and is necessary for life.
01.SC.ES.04	Record the time of day when the sun shines in different school locations and note patterns.
01.SC.ES.05	Keep a class weather chart indicating daily temperature, how windy it is, which direction wind is blowing (use visual clues), and kind of precipitation, if any.

LIFE SCIENCE

	Students will…
01.SC.LS.01	Recognize that fossils provide us with information about living things that inhabited the earth years ago.
01.SC.LS.02	Look at a variety of fossils or pictures of fossils, including plants, fish, and extinct species. Guess what living organisms they might be related to.
01.SC.LS.03	Recognize that people and other animals interact with the environment through their senses of sight, hearing, touch, smell, and taste.
01.SC.LS.04	Observe small animals in the classroom while they find food, water, shelter.
01.SC.LS.05	Talk about how people use their senses every day.
01.SC.LS.06	Recognize changes in appearance that animals and plants go through as the seasons change.
01.SC.LS.07	Observe and record changes in plants (e.g., trees, flowers, grass) on the playground and around the school during fall, winter and spring.
01.SC.LS.08	Identify the ways in which an organism's habitat provides for its basic needs (plants require air, water, nutrients, and light; animals require food, water, air and shelter).
01.SC.LS.09	Create a garden habitat for birds and butterflies. Research and plant appropriate flowers.

PHYSICAL SCIENCE

	Students will…
01.SC.PS.01	Identify objects and materials as solid, liquid or gas. Recognize that solids have a definite shape and that liquids and gases take the shape of their container.
01.SC.PS.02	Using transparent containers of very different shapes (e.g., cylinder, cone, cube) pour water from one container into another. Observe and discuss the "changing shape" of the water.
01.SC.PS.03	Observe, describe, and classify materials and objects based on shape, size, color, texture, smell.
01.SC.PS.04	Observe that the sun supplies heat and light to the earth.

TECHNOLOGY/ENGINEERING

	Students will…
01.SC.TE.01	Identify and describe the characteristics of natural materials (e.g., wood, cotton, fur, wool) and human-made materials (e.g., plastic, Styrofoam).
01.SC.TE.02	Identify and explain some possible uses for natural materials (e.g., wood, cotton, fur, wool) and human-made materials (e.g., plastic, Styrofoam).
01.SC.TE.03	Identify and describe the safe and proper use of tools and materials (e.g., glue, scissors, tape, ruler, paper, toothpicks, straws, spools) to construct simple structure.
01.SC.TE.04	Identify tools and simple machines used for a specific purpose, e.g., ramp, wheel, pulley, lever.
01.SC.TE.05	Describe how human beings use parts of the body as tools (e.g., teeth for cutting, hands for grasping and catching), and compare their use with the ways in which animals use those parts of their bodies.

GRADE TWO

SKILLS OF INQUIRY

(Tools for learning and life-long learning.)

	Students will…
02.SC.IS.01	Ask questions about objects, organisms, and events in the environment.
02.SC.IS.02	Tell about why and what would happen if?
02.SC.IS.03	Make predictions based on observed patterns.
02.SC.IS.04	Name and use simple equipment and tools (e.g., rulers, meter sticks, thermometers, hand lenses, and balances) to gather data and extend the senses.
02.SC.IS.05	Record observations and data with pictures, numbers or written statements.
02.SC.IS.06	Discuss observations with others.

EARTH/SPACE SCIENCE

	Students will…
02.SC.ES.01	Describe the weather changes from day to day and over the seasons.
02.SC.ES.02	Recognize that the sun supplies heat and light to the earth and is necessary for life.
02.SC.ES.03	Identify some events around us that have repeating patterns, including the seasons of the year, day and night.
02.SC.ES.04	Graph various kinds of weather (over a period of time) and begin to predict possible weather (seasonal) patterns. Recognize and communicate simple patterns in data.
02.SC.ES.05	Make a list of what you see outdoors and in the sky during the day. Make another list of things you see outdoors and in the sky at night. Discuss the differences between the day and night lists.

LIFE SCIENCE

	Students will…
02.SC.LS.01	Recognize changes in appearance that animals and plants go through as the seasons change.
02.SC.LS.02	Observe and record changes in plants (e.g., trees, flowers, grass) on the playground and around the school during fall, winter, and spring.
02.SC.LS.03	Identify the ways in which an organism's habitat provides for its basic needs (plants require air, water, nutrients, and light; animals require food, water, air and shelter).
02.SC.LS.04	Create a garden habitat for birds and butterflies. Research and plant appropriate flowers.
02.SC.LS.05	Recognize that fossils provide us with information about living things that inhabited the earth years ago.
02.SC.LS.06	Look at a variety of fossils or pictures of fossils, including plants, fish, and extinct species. Guess what living organisms they might be related to.
02.SC.LS.07	Recognize the people and other animals interact with the environment through their senses of sight, hearing, touch, smell and taste.
02.SC.LS.08	Observe small animals in the classroom while they find food, water, shelter, etc.
02.SC.LS.09	Talk about how people use their senses every day.

PHYSICAL SCIENCE

	Students will…
02.SC.PS.01	Recognize that under some conditions, objects can be balanced.
02.SC.PS.02	Try to make a long, thin, rectangular block of wood stand upright on each face. Note that it stands (balances) very easily on some faces, but not on all.
02.SC.PS.03	Describe the various ways that objects can move, such as in a straight line, zigzag, back-and-forth, round-and-round, fast and slow.
02.SC.PS.04	Observe objects as they push and pull them on a hard, smooth surface. Make predictions as to what direction they will move and how far they will go. Repeat using various surfaces, e.g., rough, soft.
02.SC.PS.05	Demonstrate that the way to change the motion of an object is to apply a force (give it a push or a pull). The greater the force, the greater the change in the motion of the object.
02.SC.PS.06	Use a spinning toy (e.g., top) and a rocking toy (e.g., rocking horse) to explore round-and-round motion and back-and-forth motion.

ECHNOLOGY/ENGINEERING

	Students will…
02.SC.TE.01	Identify and describe the characteristics of natural materials (e.g., wood, cotton, fur, wool) and human-made materials (e.g., plastic, Styrofoam).
02.SC.TE.02	Identify and explain some possible uses for natural materials (e.g., wood, cotton, fur, wool) and human-made materials (e.g., plastic, Styrofoam).
02.SC.TE.03	Identify and describe the safe and proper use of tools and materials (e.g., glue, scissors, tape, ruler, paper, toothpicks, straws, spools) to construct simple structure.
02.SC.TE.04	Identify tools and simple machines used for a specific purpose, e.g., ramp, wheel, pulley, lever.
02.SC.TE.05	Describe how human beings use parts of the body as tools (e.g., teeth for cutting, hands for grasping and catching), and compare their use with the ways in which animals use those parts of their bodies.

GRADE THREE

In science, students will develop an increasing knowledge and comprehensive of the environment. The program will develop in-depth understanding of the Earth's detailed characteristics, advanced knowledge of living things and properties of objects and materials. Students will be able to design comparative tests, implement test procedures, collect and record data, and analyze and communicate results.

SKILLS OF INQUIRY

(Tools for learning and life-long learning.)

	Students will…
03.SC.IS.01	Ask questions and make predictions that can be tested.
03.SC.IS.02	Select and use appropriate tools and technology (e.g., calculators, computers, balances, scales, meter sticks, graduated cylinders) in order to extend observations.
03.SC.IS.03	Keep accurate records while conducting simple investigations or experiments.
03.SC.IS.04	Conduct multiple trials to test a prediction. Compare the results of an investigation or experiment with the prediction.
03.SC.IS.05	Recognize simple patterns in data and use data to create a reasonable explanation for the results of an investigation or experiment.
03.SC.IS.06	Record data and communicate findings to others using graphs, charts, maps, models, and oral and written reports.

LIFE SCIENCE

	Students will…
03.SC.LS.01	Classify plants and animals according to the physical characteristics that they share.
03.SC.LS.02	Sort plant and animal pictures based on physical characteristics.
03.SC.LS.03	Use a dichotomous key to identify plants.
03.SC.LS.04	Identify the structures in plants (leaves, roots, flowers, stem, bark, wood) that are responsible for food production, support, water transport, reproduction, growth, and protection.
03.SC.LS.05	Observe plant/pollinator interaction and seed dispersal methods.
03.SC.LS.06	Study maple trees and to maple sugaring. Identify the structures in the maple tree and their functions.
03.SC.LS.07	Recognize that plants and animals go through life cycles that include birth, growth, development, reproduction and death.
03.SC.LS.08	Grow plants from seeds. Document the complete life cycle of the plant. Emphasize emergence of structures and the functions of these structures. Record changes in height over time. Graph the data.
03.SC.LS.09	Describe the major stages that characterize the life cycle of the bean and corn plants.
03.SC.LS.10	Using either live organisms or pictures/models, observe the changes in form during the life cycle of a butterfly or frog.

PHYSICAL SCIENCE

	Students will…
03.SC.PS.01	Differentiate between properties of objects (e.g., shape, weight) and properties of materials (e.g., color, texture, hardness).
03.SC.PS.02	Gather a variety of solid objects. Collect data on properties of these objects such as origin (man-made or natural), weight (heavy, medium, light), length, odor, color, hardness, and flexibility.
03.SC.PS.03	Compare and contrast solids, liquids, and gases based on the basic properties of each of these states of matter.
03.SC.PS.04	Design several stations, each of which demonstrates a state of matter, e.g., water table, balloon and fan table, sand and block table, etc.
03.SC.PS.05	Describe how water can be changed from one state to another by adding or taking away heat.
03.SC.PS.06	Do simple investigations with evaporation, condensation, freezing and melting. Confirm that water expands upon freezing.

03.SC.PS.07	Identify basic forms of energy (light, sound, heat, electrical, and magnetic). Recognize that energy is the ability to cause motion or create change.
03.SC.PS.08	Design and construct a simple sound-producing device that demonstrates how to change the properties of volume and pitch (e.g., home-make instruments).

TECHNOLOGY/ENGINEERING

	Students will…
03.SC.TE.01	Identify materials used to accomplish a design task based on a specific property, e.g., weight, strength, hardness, and flexibility.
03.SC.TE.02	Identify and explain the appropriate materials and tools (e.g., hammer, screwdriver, pliers, tape measure, screws, nails, and other mechanical fasteners) to construct a given prototype safely.
03.SC.TE.03	Identify a problem that reflects the need for shelter, storage, or convenience.
03.SC.TE.04	Describe different ways in which a problem can be represented, e.g., sketches, diagram, graphic organizers, and lists.
03.SC.TE.05	Develop a knowledge and understanding of the metric measurement system.

GRADE FOUR

SKILLS OF INQUIRY

(Tools for learning and life-long learning.)

	Students will…
04.SC.IS.01	Ask questions and make predictions that can be tested.
04.SC.IS.02	Select and use appropriate tools and technology (e.g., calculators, computers, balances, scales, meter sticks, graduated cylinders) in order to extend observations.
04.SC.IS.03	Keep accurate records while conducting simple investigations or experiments.
04.SC.IS.04	Conduct multiple trials to test a prediction. Compare the results of an investigation or experiment with the prediction.
04.SC.IS.05	Recognize simple patterns in data and use data to create a reasonable explanation for the results of an investigation or experiment.
04.SC.IS.06	Record data and communicate findings to others using graphs, charts, maps, models, and oral and written reports.

EARTH/SPACE SCIENCE

	Students will…
04.SC.ES.01	Describe how global patterns such as the jet stream and water currents influence local weather in measurable terms such as temperature, wind direction and speed, and precipitation.
04.SC.ES.02	Conduct an activity to illustrate convection (essential in transferring both heat and moisture around the world; drives both wind circulation and ocean currents). Discuss what happens and how it is connected to convection in both liquid and gas.
04.SC.ES.03	Differentiate between weather and climate.
04.SC.ES.04	Collect daily temperature and precipitation data, preferably by observation. Use the Internet or newspaper to collect the same data for a nearby city and a city on the west coast of the U.S. After three months, take various averages of the daily data for the three locations. Graph the data and discuss how the long-term daily weather averages begin to describe each climate.
04.SC.ES.05	Describe how water on earth cycles in different forms and in different locations, including underground and in the atmosphere.
04.SC.ES.06	Draw a diagram of the water cycle. Label evaporation, condensation, and precipitation. Explain what happens during each process.
04.SC.ES.07	Explain how air temperature, moisture, wind speed and direction, and precipitation make up the weather in a particular place and time.
04.SC.ES.08	Use a collection of classical (not digital) weather instruments that clearly show the physical principle that makes them work.
04.SC.ES.09	Distinguish among the various forms of precipitation. Bring a measured sample of snow into the classroom, allow it to melt, and compare the amount of water that results with the original measurement.

LIFE SCIENCE	
	Students will…
04.SC.LS.01	Describe the major stages that characterize the life cycle of the frog and butterfly as they go through metamorphosis.
04.SC.LS.02	Using either live organisms or pictures/models, observe the changes in form during the life cycle of a butterfly or frog.
04.SC.LS.03	Differentiate between observed characteristics of plants and animals that are fully inherited (e.g., color of flower, shape of leaves, color of eyes, number of appendages) and characteristics that are affected by the climate or environment (e.g., browning of leaves due to too much sun, biorhythms).
04.SC.LS.04	Make frequency tables of the number of students with certain inherited physical traits (e.g., eye color, hair color, earlobe free or attached).
04.SC.LS.05	Give examples of how inherited characteristics may change over time as adaptations to changes in the environment that enable organisms to survive (e.g., shape of beak or feet, placement of eyes on head, length of neck, shape of teeth, color.
04.SC.LS.06	Compare and contrast the physical characteristics of plants or animals from widely different environments (desert vs. tropical plants; aquatic vs. terrestrial animals). Explore how each is adapted to its habitat.
04.SC.LS.07	Give examples of how changes in the environment (drought, cold) have caused some plants and animals to die or move to new locations (migration).
04.SC.LS.08	Investigate how invasive species out-compete native plants (e.g., phragmites and purple loose-strife). Discuss how some native plants die as a result.

PHYSICAL SCIENCE	
	Students will…
04.SC.PS.01	Design and construct a simple sound-producing device to predict, demonstrate, and describe the properties of loudness and pitch of sound.
04.SC.PS.02	Identify the basic forms of energy (light, sound, heat, electrical, and magnetic). Recognize that energy is the ability to cause motion or create change.
04.SC.PS.03	Give examples of how energy can be transferred from one form to another.
04.SC.PS.04	Rub two pieces of wood together (mechanical energy) and observe the change in temperature of the wood.
04.SC.PS.05	Recognize that electricity in circuits requires a complete loop through which an electrical current can pass, and that electricity can produce light, heat and sound.
04.SC.PS.06	Identify and classify objects and materials that conduct electricity and objects and materials that are insulators of electricity.
04.SC.PS.07	Determine the electrical conductivity of a collection of materials by testing the materials with a simple battery/bulb circuit.
04.SC.PS.08	Explain how electromagnets can be made, and give examples of how they can be used.
04.SC.PS.09	Describe and model the basic structure of the atom, e.g., carbon and oxygen.

TECHNOLOGY/ENGINEERING	
	Students will…
04.SC.TE.01	Identify materials used to accomplish a design task based on specific property (e.g., weight, strength, hardness, and flexibility).
04.SC.TE.02	Identify and explain the appropriate materials and tools (e.g., hammer, screwdriver, pliers, tape measure, screws, nails, and other mechanical fasteners) to construct a given prototype safely.
04.SC.TE.03	Identify and explain the difference between simple and complex machines (e.g., hand can opener that includes multiple gears, wheel, wedge gear, and lever).
04.SC.TE.04	Identify a problem that reflects the need for shelter, storage or convenience.
04.SC.TE.05	Describe different ways in which a problem can be represented (e.g., sketches, diagrams, graphic organizers, and lists).
04.SC.TE.06	Identify relevant design features (e.g., size, shape, weight) for building a prototype of a solution to a given problem.
04.SC.TE.07	Compare natural systems with mechanical systems that are designed to serve similar purposes (e.g., a bird's wings as compared to an airplane's wings).
04.SC.TE.08	Apply the metric system in design projects and experiments.

GRADE FIVE

SKILLS OF INQUIRY

(Tools for learning and life-long learning.)

	Students will…
05.SC.IS.01	Ask questions and make predictions that can be tested.
05.SC.IS.02	Select and use appropriate tools and technology (e.g., calculators, computers, balances, scales, meter sticks, graduated cylinders) in order to extend observations.
05.SC.IS.03	Keep accurate records while conducting simple investigations or experiments.
05.SC.IS.04	Conduct multiple trials to test a prediction. Compare the results of an investigation or experiment with the prediction.
05.SC.IS.05	Recognize simple patterns in data and use data to create a reasonable explanation for the results of an investigation or experiment.
05.SC.IS.06	Record data and communicate findings using graphs, charts, maps, models, and oral and written reports.
05.SC.IS.07	Use APA guidelines in writing science reports.

EARTH/SPACE SCIENCE

	Students will…
05.SC.ES.01	Recognize that the earth revolves around (orbits) the sun in a year's time and that the earth rotates on its axis once approximately every 24 hours.
05.SC.ES.02	Make connections between the rotation of the earth and day/night, and the apparent movement of the sun, moon, and stars across the sky.
05.SC.ES.03	Observe and discuss the changes in length and direction of shadows during the course of the day.
05.SC.ES.04	Describe the changes that occur in the observable shape of the moon over the course of a month.
05.SC.ES.05	Observe the sky every night for 30 days. Record every night the shape of the moon and its relative location across the sky.
05.SC.ES.06	Give examples of how the cycling of water, both in and out of the atmosphere, has an effect on climate.
05.SC.ES.07	Give examples of how the surface of the earth changes due to slow processes such as erosion and weathering, and rapid processes such as landslides, volcanic eruptions, and earthquakes.
05.SC.ES.08	Recognize that the earth is part of a system called the "solar system" that includes the sun (a star), planets and many moons. The earth is the third planet from the sun in our solar system.
05.SC.ES.09	Compare and discuss erosion caused by equal amounts of water running down two slopes.
05.SC.ES.10	Create a proportional model of the solar system starting on the school playground and extending as far as possible. Demonstrate the size of objects (using a pea as the smallest planet and different size balls for the rest) and the distance between them.

LIFE SCIENCE	
	Students will…
05.SC.LS.01	Describe how organisms meet some of their needs in an environment by using behaviors (patterns of activities) in response to information (stimuli) received from the environment.
05.SC.LS.02	Recognize that some animal behaviors are instinctive (e.g., turtles burying their eggs), and other are learned (e.g., humans building fires for warmth, chimpanzees learning how to use tools).
05.SC.LS.03	Discuss how newly born sea turtles find their way to the ocean.
05.SC.LS.04	Discuss how pets are trained to learn new tricks.
05.SC.LS.05	Discuss how migrating birds navigate.
05.SC.LS.06	Discuss the reasons and methods of animal migration (e.g., birds, reptiles, mammals).
05.SC.LS.07	Observe an earthworm placed on top of soil in a container that is exposed to light. Discuss how its ability to sense light helps it survive (by burrowing) and how its structure allows it to burrow through soil.
05.SC.LS.08	Recognize that plant behaviors, such as the way seedlings' stems grow toward light and their roots grow downward in response to gravity.
05.SC.LS.09	Recognize that many plants and animals can survive harsh environments because of seasonal behaviors, e.g., in winter, some trees shed their leaves, some animals hibernate or estivate, and other animals migrate.
05.SC.LS.10	Observe how the root system and stem of a germinating bean responds to changes in light by changing their direction of growth.
05.SC.LS.11	Give examples of how organisms can cause changes in their environment to ensure survival. Explain how some of these changes may affect the ecosystem.
05.SC.LS.12	Discuss the importance of wetlands to human survival. Investigate how an invasive species changes an ecosystem.
05.SC.LS.13	Research local projects where humans are changing the environment to ensure a species' survival.
05.SC.LS.14	Describe how energy derived from the sun is used by plants to produce sugars (photosynthesis) and is transferred within a food chain from produces (plants) to consumers to decomposers.
05.SC.LS.15	Beginning with the sun as the source of energy and ending with decomposers, make a food chain. Create links that show the relationship of plants and animals in the chain. Show the direction of the flow of energy and discuss the results if various links in the chain are broken.

PHYSICAL SCIENCE	
	Students will…
05.SC.PS.01	Recognize that magnets have poles that repel and attract each other.
05.SC.PS.02	Balance ring magnets on a pencil. Note: the shape of a ring magnet obscures the locations of its poles.
05.SC.PS.03	Identify and classify objects and materials that a magnet will attract and objects and materials that a magnet will not attract.
05.SC.PS.04	Test a variety of materials with assorted magnets.
05.SC.PS.05	Recognize that sound is produced by vibrating objects and requires a medium through which to travel. Relate the rate of vibration to the pitch of the sound.
05.SC.PS.06	Use tuning forks to demonstrate the relationship between vibrations and sound.
05.SC.PS.07	Recognize that light travels in a straight line until it strikes an object or travels from one medium to another, and that light can be reflected, refracted, and absorbed.
05.SC.PS.08	Use a flashlight, mirrors, and water to demonstrate reflection and refraction.

TECHNOLOGY/ENGINEERING	
	Students will…
05.SC.TE.01	Identify materials used to accomplish a design task based on specific property, i.e., weight, strength, hardness, and flexibility.
05.SC.TE.02	Identify and explain the appropriate materials and tools (i.e., hammer, screwdriver, pliers, tape measure, screws, nails, and other mechanical fasteners) to construct a given prototype safely.
05.SC.TE.03	Identify and explain the difference between simple and complex machines, i.e., hand can opener that includes multiple gears, wheel, wedge gear, and lever.
05.SC.TE.04	Identify a problem that reflects the need for shelter, storage or convenience.
05.SC.TE.05	Describe different ways in which a problem can be represented, i.e., sketches, diagrams, graphic organizers, and lists.
05.SC.TE.06	Identify relevant design features (i.e., size, shape, weight) for building a prototype of a solution to a given problem.
05.SC.TE.07	Compare natural systems with mechanical systems that are designed to serve similar purposes, i.e., a bird's wings as compared to an airplane's wings.

GRADE SIX

Science will develop a connected view of living systems, develop in-depth views of motion of the earth, solar system and the Universe, in order to understand the properties and interactions of matter and energy. Students will develop in-depth skills using measurement devices, explorations and experimentation processes, and computer modeling of biological and physical systems.

SKILLS OF INQUIRY

(Tools for learning and life-long learning.)

Students will…

06.SC.IS.01	Formulate a testable hypothesis.
06.SC.IS.02	Design and conduct an experiment specifying variables to be changes, controlled, and measured.
06.SC.IS.03	Select appropriate tools and technology (e.g., calculators, computers, thermometers, meter sticks, balances, graduated cylinders, and microscopes), and make quantitative observations.
06.SC.IS.04	Present and explain data and findings using multiple representations, including tables, graphs, mathematical and physical models, and demonstrations.
06.SC.IS.05	Draw conclusions based on data or evidence presented in tables or graphs, and make inferences based on patterns or trends in the data.
06.SC.IS.06	Communicate procedures and results using appropriate science and technology terminology.
06.SC.IS.07	Offer explanations of procedures, and critique and revise them.
06.SC.IS.08	Use APA guidelines in writing science reports.

EARTH/SPACE SCIENCE

Students will…

06.SC.ES.01	Recognize, interpret and be able to create models of the earth's common physical features in various mapping representations, including contour maps.
06.SC.ES.02	Choose a small area of unpaved, sloping ground in the schoolyard or a park. Create a scale contour map of the area. Include true north and magnetic north.
06.SC.ES.03	Describe the layers of the solid earth, including the lithosphere, the hot convecting mantle, and the dense metallic core.
06.SC.ES.04	Use a Styrofoam ball and paint to construct a cross-section model of the earth.
06.SC.ES.05	Differentiate among radiation, conduction, and convection, the three mechanisms by which heat is transferred through the earth's system.
06.SC.ES.06	Investigate the movement of a drop of food coloring placed in water, with and without a heat source, and in different positions relative to a heat source.
06.SC.ES.07	Explain the relationship among the energy provided by the sun, the global patterns of atmospheric movement, and the temperature differences among water, land, and atmosphere.
06.SC.ES.08	Note the relationship between global wind patterns and ocean current patterns.

LIFE SCIENCE

	Students will…
06.SC.LS.01	Classify organisms into the currently recognized kingdoms according to characteristics that they share. Be familiar with organisms from each kingdom.
06.SC.LS.02	Describe diversity among living things.
06.SC.LS.03	Recognize that all organisms are composed of cells, and that many organisms are single-celled (unicellular), e.g., bacteria, yeast. In these single-celled organisms, one cell must carry out all the basic functions of life.
06.SC.LS.04	Observe, describe, record and compare a variety of unicellular organisms found in aquatic ecosystems.
06.SC.LS.05	Compare and contrast plant and animal cells, including major organelles (cell membrane, cell wall, nucleus, cytoplasm, chloroplasts, mitochondria, vacuoles).
06.SC.LS.06	Observe a range of plant and animal cells to identify the cell wall, cell membrane, chloroplasts, vacuoles, nucleus and cytoplasm when present.
06.SC.LS.07	Recognize that within cells, many of the basic functions of organisms (e.g., extracting energy from food and getting grid of waste) are carried out. The way in which cells function is similar in all living organisms.
06.SC.LS.08	Describe the hierarchical organization of multicellular organisms from cells to tissues to organs to systems to organisms.
06.SC.LS.09	Describe different types of cells in a multicellular organism and how their characteristics relate to specialized functions (e.g., blood, nerve, skin).
06.SC.LS.10	Identify the general functions of the major systems of the human body (digestion, respiration, reproduction, circulation, excretion, protection from disease, and movement, control and coordination) and describe ways that these systems interact with each other.
06.SC.LS.11	Measure, record, and interpret pulse and breathing rates with respect to various activities.
06.SC.LS.12	Develop analogies of body systems working together to manufactures objects (e.g., car, bicycle, house).
06.SC.LS.13	Record and account for areas of the skin more or less sensitive to touch.
06.SC.LS.14	Measure, record, and interpret data during different activities that take place within the body systems and explain the importance of those activities (using external temperature strips).
06.SC.LS.15	Describe the organization of multicellular organisms from cells to tissues to organs to systems and how those systems carry out life processes.
06.SC.LS.16	Describe mechanical, electrical, and chemical activities that take place within the body systems and explain the importance of those activities.
06.SC.LS.17	Demonstrate an understanding of the systems of the human body and how they function.

PHYSICAL SCIENCE

	Students will…
06.SC.PS.01	Differentiate between weight and mass, recognizing that weight is the amount of gravitational pull on an object.
06.SC.PS.02	Explain how to determine the weight of a dense object in air and in water.
06.SC.PS.03	Differentiate between volume and mass.
06.SC.PS.04	Define density.
06.SC.PS.05	Recognize that the measurement of volume and mass requires understanding of the sensitivity of measurement tools (e.g., rulers, graduated cylinders, balances) and knowledge and appropriate use of significant digits.
06.SC.PS.06	Calculate the volumes of regular objects from linear measurements. Measure the volumes of the same objects by displacement of water. Use the metric system. Discuss the accuracy limits of the procedures and how they explain any differences between the calculated volumes and the measured volumes.
06.SC.PS.07	Explain and give examples of how mass is conserved in a closed system.
06.SC.PS.08	Melt, dissolve, and precipitate various substances to observe examples of the conservation of mass.
06.SC.PS.09	Recognize that there are more than 100 elements that combine in the multitude of ways to produce compounds that make up all of the living and nonliving things that we encounter.
06.SC.PS.10	Demonstrate with atomic models (e.g., ball and stick) how atoms can combine in a large number of ways. Explain why the number of combinations is large, but still limited. Use the models to demonstrate the conservation of mass in the chemical reactions being modeled.
06.SC.PS.11	Differentiate between an atom (the smallest unit of an element that maintains the characteristics of that element) and a molecule (the smallest unit of a compound that maintains the characteristics of a compound).
06.SC.PS.12	Use atomic models (or Lego blocks, assigning various colors to various atoms) to build molecules of water, sodium chloride, carbon dioxide, ammonia, etc.
06.SC.PS.13	Give basic examples of elements and compounds.
06.SC.PS.14	Heat sugar in a crucible with an inverted funnel over it. Observe carbon residue and water vapor in the

funnel as evidence of the breakdown of components. Continue heating the carbon residue to show that carbon residue does not decompose.

TECHNOLOGY/ENGINEERING

	Students will…
06.SC.TE.01	Given a design task, identify appropriate materials (e.g., wood, paper, plastic, aggregates, ceramics, metals, solvents, adhesives) based on specific properties and characteristics (e.g., weight, strength, hardness and flexibility).
06.SC.TE.02	Identify and explain appropriate measuring tools, hand tools, and power tools used to hold, lift, carry, fasten, and separate, and explain their safe and proper use.
06.SC.TE.03	Identify and explain the safe and proper use of measuring tools, hand tools, and machines (e.g., band saw, drill press, sanders, hammer, screwdriver, pliers, tape measure, screws, nails, and other mechanical fasteners) needed to construct a prototype of an engineering design.
06.SC.TE.04	Conduct tests for weight, strength, hardness and flexibility of various materials, e.g., wood, paper, plastic, ceramics, metals.
06.SC.TE.05	Design and build a catapult that will toss a marshmallow the farthest.
06.SC.TE.06	Use a variety of hand tools and machines to change materials into new forms through forming, separating,, and combining processes that cause internal change to occur.
06.SC.TE.07	Identify and explain the steps of the engineering **design process**, e.g., identify the need or problem, research the problem, develop possible solutions, select the best possible solution(s), construct a prototype, test and evaluate, communicate the solution(s), and redesign.
06.SC.TE.08	Demonstrate methods of representing solutions to a design problem, e.g., sketches, orthographic projections, multiview drawings.
06.SC.TE.09	Describe and explain the purpose of a given prototype.
06.SC.TE.10	Identify appropriate materials, tools, and machines needed to construct a prototype of a given engineering design.
06.SC.TE.11	Explain how such design features as size, shape, weight, function, and cost limitations would affect the construction of a given prototype.
06.SC.TE.12	Identify the five elements of a universal systems model: goal, inputs, processes, outputs, and feedback.
06.SC.TE.13	Given a prototype, design a test to evaluate whether it meets the design specifications.
06.SC.TE.14	Using test results, modify the prototype to optimize the solution, e.g., bring the design closer to meeting the design constraints.
06.SC.TE.15	Communicate the results of an engineering design through a coherent written, oral or visual presentations.
06.SC.TE.16	Develop plans, including drawings with measurements and details of construction, and construct a model of the solution, exhibiting a degree of craftsmanship.
06.SC.TE.17	Apply the metric system in design projects and experiments.

XI
B.
Frameworks (Science and Technology)

Science and Technology/Engineering Curriculum Framework

May 2001

Massachusetts Department of Education
Address 350 Main Street, Malden, MA 02148
Telephone 781-338-3000 **Internet** www.doe.mass.edu

May 2001

Dear Colleagues,

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

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

- Standards are more specific, to enable teachers to design instruction and assessment more effectively. Grade spans have narrowed from Prek-4, 5-8, 9-10 to Prek-2, 3-5, 6-8, 9-10.
- The four strands in the 1995 document (Inquiry, Domains of Science, Technology and Science, and Technology and Human Affairs) are now four content strands (Earth and Space Science, Life Science, Physical Sciences, and Technology/Engineering). "Inquiry" is now to be taught with the content of each domain of science.
- High school standards: The 2001 framework has a set of standards for comprehensive, full year courses in each of the four science domains, and in Technology/Engineering. In each domain, a subset of these standards has been identified as core. Only core standards will be assessed by MCAS. In addition, a set of core standards has been identified for a two-year, grade 9 and 10 integrated science program. These standards are a subset of the core standards from each of the four science domains.
- Format: The revised document has a three-column grid for grades Prek-5 that shows the topic and the Learning Standards, Ideas for Developing Investigations and Learning Experiences, and Suggested Extensions to Learning in Technology/Engineering.
- A glossary was added for selected Prek-8 terms and a topical outline was included.

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

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

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

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

Sincerely,

David P. Driscoll
Commissioner of Education

Acknowledgments

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

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

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Introduction

The Massachusetts Science and Technology/Engineering Curriculum Framework is one of seven curriculum frameworks that advance Massachusetts's educational reform in learning, teaching, and assessment. It was created and has been revised by teachers and administrators of science and technology/engineering programs in prekindergarten through grade 12 school districts, by college and university professors, and by engineers and scientists in the various domains working with staff from the Department of Education. Its purpose is to guide teachers and curriculum coordinators about what content should be taught from PreK through high school.

Organization of the Framework

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

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

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

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

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

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

Development of the standards

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

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

The draft produced by the revision panel was released for public comment in August 1999. Based on comments on this draft from science and technology/engineering teachers and other educators, further revisions were made, particularly at the high school level. Groups of high school science teachers in each domain of science developed a comprehensive set of standards for a course in each domain from which core standards were chosen for discipline-specific assessments. Groups of technology/engineering educators also contributed to the development of a comprehensive set of standards and core standards for the technology/engineering course at the high school level.

Purpose and Nature of Science and Technology/Engineering

The purpose of science and technology/engineering education

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

The nature of science

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

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

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

The nature of technology/engineering

Technology/engineering seeks different ends from those of science. Engineering strives to design and manufacture useful devices or materials, defined as technologies, whose purpose is to increase our efficacy in the world and/or our enjoyment of it. Can openers are technology, as are microwave ovens, microchips, steam engines, camcorders, safety glass, zippers, polyurethane, the Golden Gate Bridge, much of Disney World, and the “Big Dig” in Boston. Each of these, and innumerable other examples of technology/engineering, emerges from the scientific knowledge, imagination, persistence, talent, and ingenuity of its practitioners. Each technology represents a designed solution, usually created in response to a specific practical problem. As with science, direct engagement with the phenomena in question is central to the definition of these problems and their successful solution.

The relationship between science and technology/engineering

In spite of their different ends, science and technology have become closely, even inextricably, related in many fields. The instruments that scientists use, such as the microscope, balance, and chronometer, result from technology/engineering. Scientific ideas, such as the laws of motion, the relationship between electricity and magnetism, the atomic model, and the model of DNA, have contributed to improvement of the internal combustion engine, power transformers, nuclear power, and human gene therapy. In some of the most sophisticated efforts of scientists and engineers, the boundaries are so blurred that the designed device allows us to discern heretofore unnoticed natural patterns while the accounting for those patterns makes it possible to continue to develop the device. In these instances, scientists and engineers are engaged together in extending knowledge.

Inquiry and Experimentation

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

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

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

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

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

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

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

Skills of Inquiry

Grades PreK-2

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

Grades 3-5

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

Grades 6-8

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

High School

- Pose questions and state hypotheses based on prior scientific observations, experiments, and knowledge.

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

Guiding Principles

Guiding Principle I

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

Students benefit from studying science and technology/engineering throughout all their years of schooling. They should learn the fundamental concepts of each domain of science, as well as the connections across those domains and to technology/engineering. The purpose of this framework is to delineate what knowledge is essential if students are to attain understanding of basic scientific concepts before graduation from high school.

Students in grades PreK-5 should have science instruction on a regular basis every year. Approximately one-quarter of their science time in PreK-5 should be devoted to technology/engineering. In middle school, they should have a full year of science study every year. Within the grades 6-8 span, students should also have one year of technology/engineering education in addition to three years of science. Schools may choose to offer technology/engineering as a semester course in each of two years; as a full year course in grade 8; or in three units, one each year in grades 6, 7, and 8. In grades 9 and 10, all students should have full-year laboratory-based science courses, and in grades 11 and 12, they should take more science courses or pursue advanced study in science through advanced placement courses, independent research, or study of special topics. In technology/engineering at the high school level, students may take semester- or year-long coursework in this area to complement or extend their study of science and mathematics.

Guiding Principle II

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

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

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

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

Guiding Principle III

Science and technology/engineering are integrally related to mathematics.

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

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

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

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

Because of the importance of mathematics to science and technology/engineering, all teachers, curriculum coordinators, and others who help implement this framework must be aware of the level of mathematical knowledge needed for each science course at the high school level and ensure that the appropriate mathematical knowledge has already been taught or, at the least, is being taught concurrently.

Guiding Principle IV

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

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

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

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

Guiding Principle V

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

Investigations introduce students to the nature of original research, increase students' understanding of scientific and technological concepts, promote skill development, and provide entry points for all learners. Teachers should establish the learning goals and context for an experiment, guide student activities, and help students focus on important ideas and concepts.

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

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

Guiding Principle VI

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

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

Guiding Principle VII

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

Assessment assists teachers in improving classroom practice, planning curricula, developing self-directed learners, and reporting student progress. It provides students with information about how their knowledge and skills are developing and what can be done to improve them. It lets parents know how well their children are doing and what needs to be done to help them do better. In essence, assessment reflects classroom expectations and shows the outcomes of student learning.

Assessments come in many forms. These include paper-and-pencil testing, performance testing, interviews, and portfolios, as well as less formal inventories such as regular observation of student responses to instruction. Diagnostic information gained from multiple forms of assessment enables teachers to adjust their day-to-day and week-to-week practices to foster greater student achievement.

The framework's learning standards are a key resource for setting knowledge and performance standards. In helping students achieve standards, teachers should use a variety of question formats: short answer, multiple choice, and open ended. They should also develop performance-based assessments that allow students to demonstrate what they have learned in the context of solving a complex problem. This kind of assessment requires students to refine a problem, devise a strategy to solve it, conduct sustained work, and deal with both complex concepts and discrete facts.

Guiding Principle VIII

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

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

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

Guiding Principle IX

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

An effective curriculum that addresses the learning standards of this framework needs to be planned as a unitary PreK-12 enterprise. Teachers need to work across grade levels and across schools to ensure that the curriculum is a coherent whole. There needs to be agreement among teachers in different classrooms and at different levels about what is to be taught in given grades. For example, middle school teachers should be able to expect that students coming from different elementary schools within a district share a common set of experiences and understandings in science and technology/engineering, and that the students they send on to high school will be well-prepared for what comes next. In order for this expectation to be met, middle school teachers will need to plan curricula in common with their elementary and high school colleagues and district staff. To facilitate planning, districts will need to provide their staff with adequate planning time and resources.

Guiding Principle X

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

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

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

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

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

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

Strand 1: Earth and Space Science

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

In grades PreK-2, students are naturally interested in everything around them. This curiosity leads them to observe, collect, and record information about the earth and about objects visible in the sky. Teachers should encourage their students' observations without feeling compelled to offer the precise scientific reasons for these phenomena. Young children bring these experiences to school and learn to extend and focus their explorations. In the process, they learn to work with tools like magnifiers and simple measuring devices. The learning standards at this level fall under the topics of *Earth's Materials, Weather, Sun as a Source of Heat and Light,* and *Periodic Phenomena.*

In grades 3-5, students explore properties of earth materials and how they change. They conduct tests to classify materials by observed properties, make and record sequential observations, note patterns and variations, and look for factors that cause change. Students observe weather phenomena and describe them quantitatively using simple tools. They study the water cycle, including the forms and locations of water. The focus is on having students generate questions, investigate possible solutions, make predictions, and evaluate their conclusions. Learning standards fall under the topics of *Rocks and Their Properties, Soil, Weather, Water Cycle, Earth's History,* and *The Earth in the Solar System.*

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

At this level, students should recognize the interacting nature of the earth's four major systems: the geosphere, hydrosphere, atmosphere, and biosphere. They should begin to see how the earth's movement affects both the living and nonliving components of the world. Attention shifts from the properties of particular objects toward an understanding of the place of the earth in the solar system and changes in the earth's composition and topography over time. Middle school students grapple with the importance of and methods of obtaining direct and indirect evidence to support current thinking. They recognize that new technologies and observations change our explanations about how things in the natural world behave. Learning standards fall under the topics of *Mapping the Earth, Earth's Structure, Heat Transfer in the Earth System, Earth's History,* and *The Earth in the Solar System.*

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

Earth and Space Science

Please note: The technology/engineering standards for grades PreK-5 are on page 55.

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences	Suggested Extensions to Learning in Technology/Engineering
Grades PreK-2			**Earth and Space Science**
Earth's Materials	1. Recognize that water, rocks, soil, and living organisms are found on the earth's surface.	• Walk around the playground observing and discussing where water, rocks, soil, and living organisms are found.	• Identify characteristics shared by naturally occurring rocks and manmade concrete. (T/E 1.1)
	2. Understand that air is a mixture of gases that is all around us and that wind is moving air.	• Use a hand pump to inflate a basketball. Observe and discuss how and why the basketball gets larger as you add more air. (Air takes up space.)	• Design a kite and identify which materials would be used for its construction. Classify them as natural or manmade materials. Build the kite and fly it outside. (T/E 1.1, 1.2)
Weather	3. Describe the weather changes from day to day and over the seasons.	• Keep a class weather chart indicating daily temperature, how windy it is, which direction wind is blowing (use visual clues), and kind of precipitation, if any.	• Design and build a tool that could be used to show wind direction (wind sock). (T/E 1.3)
The Sun as a Source of Light and Heat	4. Recognize that the sun supplies heat and light to the earth and is necessary for life.	• Record the time of day when the sun shines in different school locations and note patterns.	• Design a shade for the window to keep the room cool in the summer or to keep the sun out for television viewing. (T/E 1.1, 1.3)
Periodic Phenomena	5. Identify some events around us that have repeating patterns, including the seasons of the year, day and night.	• Make a list of what you see outdoors and in the sky during the day. Make another list of things	• Use a thermometer to record the temperature from morning to noon over

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences	Suggested Extensions to Learning in Technology/Engineering
Grades PreK-2			**Earth and Space Science**
		you see outdoors and in the sky at night. Discuss the differences between the day and night lists.	several weeks and discuss any patterns that emerge. (T/E 2.1)

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences	Suggested Extensions to Learning in Technology/Engineering
Grades 3-5			**Earth and Space Science**
Rocks and Their Properties	1. Give a simple explanation of what a mineral is and some examples, e.g., quartz, mica.	• Observe and describe the characteristics of ore minerals such as magnetite and hematite (two sources of iron).	• Design a flowchart to demonstrate how silica from sand is used to make glass. (T/E 2.2)
	2. Identify the physical properties of minerals (hardness, color, luster, cleavage, and streak), and explain how minerals can be tested for these different physical properties.	• Acquire a collection of minerals that includes (a) duplicates of the same mineral, somewhat different in appearance (size, shape, exact color) and (b) samples of minerals that look similar but are actually different. Examine minerals using a hand lens. Look for and record similarities and differences such as heaviness, color, texture, crystal shapes, luster, surface patterns, etc. Sort as accurately as possible. Report total number of different minerals present, and how many duplicates, if any, of each type.	• Use simple tools to test for hardness, e.g., Moh's Scale of Hardness. (T/E 1.1)
	3. Identify the three categories of rocks (metamorphic, igneous, and sedimentary) based on how they are formed, and explain the natural and physical processes that create these rocks.	• Examine rocks collected from the schoolyard or a field trip location, or brought in from home. Sort rocks into igneous, metamorphic, or sedimentary based on their physical properties.	• Discuss the use of rocks in construction based on their physical properties. Test the hardness of various types of rocks used in construction. (T/E 1.1)
Soil	4. Explain and give examples of the ways in which soil is formed (the weathering of rock by water and wind and from the	• Observe sand with a hand lens. Note how particles resemble minerals. Observe topsoil with a	• Design and construct a composting bin being sure to

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences	Suggested Extensions to Learning in Technology/Engineering
Grades 3-5			**Earth and Space Science**
	decomposition of plant and animal remains).	hand lens. Look for fragments of organisms. Note differences in color, texture, odor, and clumping due to organic components vs. pure sand. Mix topsoil and sand together in various proportions to represent samples of types of soils.	keep design considerations in mind, e.g., aeration, resistance to rot, etc. (T/E 1.2, 2.1-2.3)

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences	Suggested Extensions to Learning in Technology/Engineering
Grades 3-5			**Earth and Space Science**
Soil (cont.)	5. Recognize and discuss the different properties of soil, including color, texture (size of particles), the ability to retain water, and the ability to support the growth of plants.	• Design an experiment to find out if different soil samples retain different amounts of water. Explain how the properties of the particles affect the large-scale properties of the soil like water retention and speed of water flow. Discuss how a soil's water retention affects the animals and plants that live in it.	• Use sieves of different mesh sizes to separate coarse and fine materials in a soil sample. Approximate the ratio of fine to coarse material in the sample. (T/E 1.1, 1.2)
Weather	6. Explain how air temperature, moisture, wind speed and direction, and precipitation make up the weather in a particular place and time.	• Use a collection of classical (not digital) weather instruments that clearly show the physical principle that makes them work. Collection includes thermometer, barometer, rain gauge, hygrometer, and anemometer. Note: A "homemade" instrument is often too inaccurate and unreliable to be a good weather teaching aid by itself. However, when used in combination with a working instrument of similar simple design, it can help students grasp both an important physical concept and its relevance to weather.	• Using measuring tools or graph paper, sketch a scale drawing of the front view of an object used to measure weather. (T/E 2.3) • Design and construct a variety of simple instruments that could be used to measure weather. Discuss how their design suits their purpose. (T/E 2.1-2.4) • Explain how tools of technology such as a hammer, screwdriver, pliers, tape measure, screws, nails, and other mechanical fasteners can be used to make or build weather instruments. (T/E 1.1)

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences	Suggested Extensions to Learning in Technology/Engineering
Grades 3-5			**Earth and Space Science**
	7. Distinguish among the various forms of precipitation (rain, snow, sleet, and hail), making connections to the weather in a particular place and time.	• Measure various forms of precipitation. Bring a measured sample of snow into the classroom, allow it to melt, and compare the amount of water that results with the original measurement.	• Construct various weather station instruments (e.g., wind gauge, barometer, anemometer), record data from them, and make conclusions. (T/E 1.1, 1.2, 2.1, 2.2, 2.3)

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences	Suggested Extensions to Learning in Technology/Engineering
Grades 3-5			**Earth and Space Science**
Weather (cont.)	8. Describe how global patterns such as the jet stream and water currents influence local weather in measurable terms such as temperature, wind direction and speed, and precipitation.	• An activity to illustrate convection (essential in transferring both heat and moisture around the world; drives both wind circulation and ocean currents.) Freeze a dark solution of food coloring and water in an ice cube tray. Float a colored ice cube on water in a transparent container. Discuss what happens, and how it is connected to convection in both liquid and gas.	• To make a model of the jet stream, fill a jar halfway with warm water. Sprinkle some pepper into the water to represent nutrients on the ocean floor. Put a colored ice cube into the jar. Students should draw and describe their observations. (T/E 2.2)
	9. Differentiate between weather and climate.	• Collect daily temperature and precipitation data, preferably by observation, at your school. At the same time use the internet or a newspaper to collect the same data for a nearby city and a city on the west coast of the U.S. After three months, take various averages of the daily data for the three locations. Graph the data. Discuss how the long-term daily weather averages begin to describe each climate.	• Discuss tools used to measure everyday weather compared with tools used in determining climate. (T/E 1.2) • Use a thermometer and barometer to compare conditions indoors and outdoors. (T/E 2.4)
The Water Cycle	10. Describe how water on earth cycles in different forms and in different locations, including underground and in the atmosphere.	• Draw a diagram of the water cycle. Label evaporation, condensation, and precipitation. Explain what happens during each process.	• Design and build a terrarium to demonstrate the water cycle. (T/E 1.2, 2.1-2.3)

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences	Suggested Extensions to Learning in Technology/Engineering
Grades 3-5			**Earth and Space Science**
	11. Give examples of how the cycling of water, both in and out of the atmosphere, has an effect on climate.		

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences	Suggested Extensions to Learning in Technology/Engineering
Grades 3-5			**Earth and Space Science**
Earth's History	12. Give examples of how the surface of the earth changes due to slow processes such as erosion and weathering, and rapid processes such as landslides, volcanic eruptions, and earthquakes.	• To demonstrate the influence of vegetation on erosion, put soil in two shallow rectangular baking pans. Cover one pan with a layer of sod. Elevate one end of each pan. Compare and discuss the erosion caused by equal amounts of water running down each slope.	• Identify one manmade attribute that slows the erosion process (e.g., hay bales at a construction site, silt fence protecting sand dunes) and one attribute that accelerates it (e.g., paving a parking lot, cutting trees). Relate these to natural systems. (T/E 2.1, 2.4)
The Earth in the Solar System	13. Recognize that the earth is part of a system called the "solar system" that includes the sun (a star), planets, and many moons. The earth is the third planet from the sun in our solar system.	• Create a proportional model of the solar system starting on the school playground and extending as far as possible. Demonstrate the size of objects (use a pea as the smallest planet, and different size balls for the rest) and the distance between them.	
	14. Recognize that the earth revolves around (orbits) the sun in a year's time and that the earth rotates on its axis once approximately every 24 hours. Make connections between the rotation of the earth and day/night, and the apparent movement of the sun, moon, and stars across the sky.	• Observe and discuss the changes in length and direction of shadows during the course of a day.	• Design and build a sundial and use it to determine the time of day. Explore how accurate it is over time. Determine the conditions under which the sundial does and does not work. (T/E 1.1, 1.2, 2.3)
	15. Describe the changes that occur in the observable shape of the moon over the	• Observe the sky every night for 30 days. Record every night the shape	• Design and create a calendar that illustrates the phases of

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences	Suggested Extensions to Learning in Technology/Engineering
Grades 3-5			**Earth and Space Science**
	course of a month.	of the moon and its relative location across the sky (record the date of the month and the time of observation each time as well).	the moon. (T/E 2.2, 2.3)

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences
Grades 6-8		**Earth and Space Science**
Mapping the Earth	1. Recognize, interpret, and be able to create models of the earth's common physical features in various mapping representations, including contour maps.	• Choose a small area of unpaved, sloping ground in the schoolyard or a park. Create a scale contour map of the area. Include true north and magnetic north.
Earth's Structure	2. Describe the layers of the solid earth, including the lithosphere, the hot convecting mantle, and the dense metallic core.	• Use a Styrofoam ball and paint to construct a cross-section model of the earth.
Heat Transfer in the Earth System	3. Differentiate among radiation, conduction, and convection, the three mechanisms by which heat is transferred through the earth's system.	• Investigate the movement of a drop of food coloring placed in water, with and without a heat source, and in different positions relative to a heat source.
	4. Explain the relationship among the energy provided by the sun, the global patterns of atmospheric movement, and the temperature differences among water, land, and atmosphere.	• Note the relationship between global wind patterns and ocean current patterns.
Earth's History	5. Describe how the movement of the earth's crustal plates causes both slow changes in the earth's surface (e.g., formation of mountains and ocean basins) and rapid ones (e.g., volcanic eruptions and earthquakes).	• Use the Pangaea map to understand plate movement. • Research and map the location of volcanic or earthquake activity. Relate these locations to the locations of the earth's tectonic plates.
	6. Describe and give examples of ways in which the earth's surface is built up and torn down by natural processes, including deposition of sediments, rock formation, erosion, and weathering.	• Observe signs of erosion and weathering in local habitats and note seasonal changes. • Visit local sites following storm events and observe changes.
	7. Explain and give examples of how physical evidence, such as fossils and surface features of glaciation, supports theories that the earth has evolved over geologic time.	• Make a timeline showing index fossils. Discuss which of these fossils are actually found in New England. Discuss why some may be missing from local rocks.
The Earth in the Solar System	8. Recognize that gravity is a force that pulls all things on and near the earth toward the center of the earth. Gravity plays a major role in the formation of the planets, stars, and solar system and in determining their motions.	• Observe the speed at which objects of various mass drop from a common height. Use a chronometer to accurately measure time and plot the data as mass versus time necessary to reach the ground.
	9. Describe lunar and solar eclipses, the observed moon phases, and tides. Relate them to the relative positions of the earth,	• Use globes and a light source to explain why high

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences
Grades 6-8		**Earth and Space Science**
	moon, and sun.	tides on two successive mornings are typically about 25 hours (rather than 24) apart.

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences
Grades 6-8		**Earth and Space Science**
	10. Compare and contrast properties and conditions of objects in the solar system (i.e., sun, planets, and moons) to those on Earth (i.e., gravitational force, distance from the sun, speed, movement, temperature, and atmospheric conditions).	• Using light objects such as balloons or basketballs, and heavy objects such as rocks, make models that show how heavy a 1 kg pumpkin would seem to you on the surface of the moon, Mars, Earth, and Jupiter.
	11. Explain how the tilt of the earth and its revolution around the sun result in an uneven heating of the earth, which in turn causes the seasons.	
	12. Recognize that the universe contains many billions of galaxies, and that each galaxy contains many billions of stars.	• Count the number of stars you can see with your naked eye in a small group such as the Pleiades. Repeat with low power binoculars. Repeat again with telescope or powerful binoculars. Research the number of stars present. Discuss the meaning of your answers.

Weather Stations

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

Earth and Space Science, Grades 3-5

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

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

Several weeks later, the weather station that the students had created was in operation, and they recorded data twice a day. They used a class-made anemometer and wind vane to observe wind direction and speed, a commercial thermometer to observe temperature, and a rain gauge to observe precipitation. The class also measured the air pressure with a handmade barometer that a parent had helped one group construct and recorded visible cloud formations.

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

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

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

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

Assessment Strategies

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

Science Learning Standards

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

Technology/Engineering Learning Standards

1.1 Identify materials used to accomplish a design task based on a specific property, i.e., weight, strength, hardness, and flexibility.

1.2 Identify and explain the appropriate materials and tools (e.g., hammer, screwdriver, pliers, tape measure, screws, nails, and other mechanical fasteners) to construct a given prototype safely.

2.1 Identify relevant design features (e.g., size, shape, weight) for building a prototype of a solution to a given problem.

Earth and Space Science Learning Standards for a Full First-Year Course in Grade 9 or 10

1. Matter and Energy in the Earth System

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

1.12 Describe the effects of longshore currents, storms, and artificial structures (e.g., jetties, sea walls) on coastal erosion in Massachusetts.
1.13 Explain what causes the tides and describe how they affect the coastal environment.

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

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

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

2. The Earth's Sources of Energy

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

2.1 Recognize, describe, and differentiate between renewable (e.g., solar, wind, water, biomass) and nonrenewable (e.g., fossil fuels, nuclear [Ura-235]) sources of energy.
2.2 Explain the advantage and limitations of renewable sources of energy.
2.3 Explain the advantage and limitations of nonrenewable sources of energy.
2.4 Describe ways in which people have tried to control the use of renewable and nonrenewable sources of energy, e.g., scientific advances, prices.
2.5 Describe the effects on the environment of using both renewable and nonrenewable sources of energy.
2.6 Describe ways in which scientists are addressing effects on the environment of using both renewable and nonrenewable sources of energy, e.g., creation of new technologies.

3. Earth Processes and Cycles

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

3.1 Explain that weather is the most significant source of erosion and how both physical and chemical weathering lead to the formation of sediments and soils, affect the shape of rocks, and create specific landscapes depending on what weathering process is dominant under a specific climate.
3.2 Describe how glaciers, gravity, wind, temperature changes, waves, and rivers cause weathering and erosion. Give examples of how the effects of these processes can be seen in our local environment. *
3.3 Explain the nitrogen and carbon cycles and their roles in the improvement of soils for agriculture.
3.4 Describe the evolution of the atmosphere.
3.5 Describe how the oceans store carbon dioxide as dissolved HCO_3 and $CaCO_3$ precipitate.

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

3.6 Explain how water flows into and through a watershed, e.g., aquifers, wells, porosity, permeability, water table, capillary water, runoff. *
3.7 Compare and contrast the processes of the hydrologic cycle including evaporation, condensation, precipitation, surface runoff and groundwater percolation, infiltration, and transpiration.

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

3.8 Describe the rock cycle, and the processes that are responsible for the formation of igneous, sedimentary, and metamorphic rocks. Compare the physical properties of these rock types. *
3.9 Compare the physical properties and the mineral combinations found in rocks.
3.10 Explain how the composition and arrangement of atoms determine a mineral's physical and chemical characteristics.

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

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

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

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

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

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

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

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

3.16 Explain how the magnetic field of the earth is produced.

3.17 Explain how the Van Allen Belts protect the biosphere

3.18 Explain how paleomagnetic patterns, preserved in rocks, provide evidence of the earth's magnetic field over geologic time.

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

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

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

3.21 Relate the effects of sudden seafloor movements to the generation of tsunamis.

3.22 Provide examples of how societies have been affected by tectonic activity (e.g., hazards from eruptions and earthquakes, bedrock type and soil conditions, building designs).

4. The Origin and Evolution of the Universe

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

4.1 Explain the Big Bang Theory and discuss the evidence that supports it (background radiation, and Relativistic Doppler effect ~ red shift).

4.2 Define the unit of distance called a light year.

Broad Concept: Gravity influences the formation and life cycles of galaxies, including our own Milky Way Galaxy, stars, planetary systems, and residual material left from the creation of the solar system. These objects move in regular patterns under the influence of gravity.

4.3 Use the Hertzsprung-Russell Diagram to explain the life histories of stars.

4.4 Compare and contrast the final three outcomes of stellar evolution based on mass (black hole, neutron star, white dwarf).

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

4.5 Compare and contrast the motions of rotation and revolution of orbiting bodies, e.g., day, year, solar/lunar eclipses. Describe the influence of gravity and inertia on these motions.

4.6 Explain Kepler's Laws of Motion.

4.7 Compare and contrast the various instrumentation used to study deep space and the solar system, e.g., refracting telescope, reflecting telescope, radio telescope, spectrophotometer.

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

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

Strand 2: Life Science (Biology)

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

As Piaget noted, young children tend to describe anything that moves as *alive.* For purposes of working with young children, who do not yet understand the continuity of life (e.g., from seed to seedling to tree to log), *living* can be defined as anything that is alive or has ever been alive (e.g., muskrat, flower, roadkill, log) and *nonliving* can be defined as anything that is not now and has never been alive (e.g., rock, mountain, glass, wristwatch). Over time, students refine their intuitive understanding. They begin to include in their definition of *living* such behaviors as eating, growing, and reproducing. Young children learn to use their senses to observe and then describe the natural world. Noticing differences and similarities and grouping organisms based on some common features is fundamental to the life science curriculum at this grade span. For a more in-depth discussion of this issue, please refer to the National Science Education Standards under Content Standard C: Developing Student Understanding (www.nap.edu/readingroom/books/nses/html/6c.html).

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

As students enter the middle school grades, the emphasis changes from observation and description of individual organisms to the development of a more connected view of biological systems. Middle school students begin to study biology at the microscopic level without delving into the biochemistry of cells. They learn that organisms are composed of cells and that some organisms are unicellular and must therefore carry out all of the necessary processes for life within that single cell. Other organisms, including human beings, are multicellular, with cells working together. Students should observe that cells of multicellular organisms can be physically very different from each other and relate that fact to the specific role that each cell has in the organisms (specialization). For example, cells of the eye or the skin or the tongue look different and do different things. Middle school students develop the understanding that the human body has organs, each of which has a specific function of its own, and that these organs together create systems that interact with each other to maintain life. As is outlined in the National Science Education Standards, students should be exposed in a general way to the systems of the human body, but are not expected to develop a detailed understanding at this grade level. Middle school students also examine the hierarchical organization of multicellular organisms and the roles and relationships that organisms occupy in an ecosystem.

At the macroscopic level, students focus on the interactions that occur within ecosystems. They explore the interdependence of living things, specifically the dependence of life on photosynthetic organisms such as plants, which in turn depend upon the sun as their source of energy. Students use mathematics to calculate rates of growth, derive averages and ranges, and represent data graphically to describe and interpret ecological concepts. The standards for grades 6-8 fall under the topics of *Classification of Organisms, Structure and Function of Cells, Systems in Living Things, Reproduction and Heredity, Evolution and Biodiversity, Living Things and Their Environment, Energy and Living Things,* and *Changes in Ecosystems Over Time.*

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

The theory of organic evolution is fundamental to understanding modern biology. It provides a framework for explaining why there are so many different kinds of organisms on earth; why organisms of distantly related species share biochemical, anatomical, and functional characteristics; why species become extinct; and how different kinds of organisms are related to one another.

Life Science (Biology)

Please note: The technology/engineering standards for grades PreK-5 are on page 55.

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences	Suggested Extensions to Learning in Technology/Engineering
Grades PreK-2			**Life Science**
Characteristics of Living Things	1. Recognize that animals (including humans) and plants are living things that grow, reproduce, and need food, air, and water.	• Draw and record the growth of a plant grown from seeds with different light exposures (vary the duration and intensity of light exposure).	• Design and construct a habitat for a living organism that meets its needs for food, air and water. (T/E 1.2, 1.2, 2.3)
	2. Differentiate between living and nonliving things. Group both living and nonliving things according to the characteristics that they share.	• Compare and contrast groups of animals (e.g., insects, birds, fish, or mammals) and look at how animals in these groups are more similar to one another than to animals in other groups.	
Life Cycles	3. Recognize that plants and animals have life cycles, and that life cycles vary for different living things.	• Using either live organisms or pictures/models, observe the changes in form during the life cycle of a butterfly or frog. • Discuss the life cycle of a tree.	• Design and build a habitat for a living organism that can be modified to meet the changing needs of the organism during its life cycle. (T/E 1.1, 1.2)
Heredity	4. Describe ways in which many plants and animals closely resemble their parents in observed appearance.	• Look at and discuss pictures of animals from the same species. Observe and discuss how they are alike and how they are different.	
Evolution and Biodiversity	5. Recognize that fossils provide us with information about living things that inhabited the earth years ago.	• Look at a variety of fossils or pictures of fossils, including plants, fish, and extinct species. Guess what living organisms they might be related to.	• Make a fossil print of plant leaves using clay or putty. (T/E 1.1, 1.2)

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences	Suggested Extensions to Learning in Technology/Engineering
Grades PreK-2			**Life Science**
Living Things and Their Environment	6. Recognize that people and other animals interact with the environment through their senses of sight, hearing, touch, smell, and taste.	• Observe small animals in the classroom while they find food, water, shelter, etc. • Talk about how people use their senses every day.	• Design and build an ant farm. Observe how ants use their senses and how they communicate to each other the location of a food source. (T/E 1.1, 1.2, 1.3)

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences	Suggested Extensions to Learning in Technology/Engineering
Grades PreK-2			**Life Science**
Living Things and Their Environment (cont.)	7. Recognize changes in appearance that animals and plants go through as the seasons change.	• Observe and record changes in plants (e.g., trees, flowers, grass) on the playground and around the school during fall, winter, and spring.	• Visit a maple syrup manufacturing facility. Discuss the sap-to-maple syrup process and the seasonal life cycle of a tree. (T/E 1.1, 1.2)
	8. Identify the ways in which an organism's habitat provides for its basic needs (plants require air, water, nutrients, and light; animals require food, water, air, and shelter).	• Create a garden habitat for birds and butterflies. Research and plant appropriate flowers.	• Using simple tools and materials, have students draw pictures of their houses and an animal's habitat. Discuss differences and similarities. (T/E 1.3)

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences	Suggested Extensions to Learning in Technology/Engineering
Grades 3-5			**Life Science**
Characteristics of Plants and Animals	1. Classify plants and animals according to the physical characteristics that they share.	• Sort plant and animal pictures based on physical characteristics. • Use a dichotomous key to identify plants.	• Create a simple chart to classify plants and animals that are common to the school's geographical area. (T/E 2.2)
Plant Structures and Functions	2. Identify the structures in plants (leaves, roots, flowers, stem, bark, wood) that are responsible for food production, support, water transport, reproduction, growth, and protection.	• Observe plant/pollinator interaction and seed dispersal methods. • Study maple trees and go maple sugaring. Identify the structures in the maple tree and their functions.	• Collect plants. Make a detailed drawing of a plant. Identify and label its major structures, i.e., leaves, flowers, stems, roots, seeds. Describe the function of each structure. (T/E 2.2, 2.3)
	3. Recognize that plants and animals go through predictable life cycles that include birth, growth, development, reproduction, and death.	• Grow plants from seed. Document the complete life cycle of the plant. Emphasize emergence of structures and the functions of these structures. Record changes in height over time. Graph the data.	• Design and construct a habitat for a small animal (e.g., insect, butterfly, frog) that has adequate space, and contains the necessities for survival. The habitat should allow for observation of the animal as it goes through the stages of its life cycle. (T/E 1.1, 1.2, 2.1-2.3)
	4. Describe the major stages that characterize the life cycle of the frog and butterfly as they go through metamorphosis.	• Using either live organisms or pictures/ models, observe the changes in form during the life cycle of a butterfly or frog.	
	5. Differentiate between observed characteristics of plants and	• Make frequency tables of the number of students with certain	

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences	Suggested Extensions to Learning in Technology/Engineering
Grades 3-5			**Life Science**
	animals that are fully inherited (e.g., color of flower, shape of leaves, color of eyes, number of appendages) and characteristics that are affected by the climate or environment (e.g., browning of leaves due to too much sun, language spoken).	inherited physical traits, e.g., eye color, hair color, earlobe free or attached.	

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences	Suggested Extensions to Learning in Technology/Engineering
Grades 3-5			**Life Science**
Adaptations of Living Things	6. Give examples of how inherited characteristics may change over time as adaptations to changes in the environment that enable organisms to survive, e.g., shape of beak or feet, placement of eyes on head, length of neck, shape of teeth, color.	• Compare and contrast the physical characteristics of plants or animals from widely different environments (desert vs. tropical plants, aquatic vs. terrestrial animals). Explore how each is adapted to its habitat.	• Discuss how engineers design things by using their knowledge of the way that animals move, e.g., birds and wings influence airplane design, tails and fins of aquatic animals influence boat design. (T/E 2.4)
	7. Give examples of how changes in the environment (drought, cold) have caused some plants and animals to die or move to new locations (migration).	• Investigate how invasive species out-compete native plants, e.g., phragmites and purple loosestrife. Discuss how some native plants die as a result.	
	8. Describe how organisms meet some of their needs in an environment by using behaviors (patterns of activities) in response to information (stimuli) received from the environment. Recognize that some animal behaviors are instinctive (e.g., turtles burying their eggs), and others are learned (e.g., humans building fires for warmth, chimpanzees learning how to use tools).	• Discuss how newly born sea turtles find their way to the ocean. • Discuss how pets are trained to learn new tricks. • Discuss how migrating birds navigate. • Discuss the actions that coastal species take to adjust to the changing level of the tide. • Observe an earthworm placed on top of soil in a container that is exposed to light. Discuss how its ability to sense light helps it survive (by burrowing) and how its structure allows it to burrow through soil.	

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences	Suggested Extensions to Learning in Technology/Engineering
Grades 3-5			**Life Science**
	9. Recognize plant behaviors, such as the way seedlings' stems grow toward light and their roots grow downward in response to gravity. Recognize that many plants and animals can survive harsh environments because of seasonal behaviors, e.g., in winter, some trees shed leaves, some animals hibernate, and other animals migrate.	• Set a germinating bean in a glass filled with water next to an asymmetric source of light. Allow the root and stem to grow a few inches. Rotate the bean so that the roots are now touching the water at an angle and the stem is away from the light source. Observe how the root system and stem respond to this change by changing their direction of growth.	

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences	Suggested Extensions to Learning in Technology/Engineering
Grades 3-5			**Life Science**
Adaptations of Living Things (cont.)	10. Give examples of how organisms can cause changes in their environment to ensure survival. Explain how some of these changes may affect the ecosystem.	• Discuss the importance of wetlands to human survival. • Investigate how an invasive species changes an ecosystem. • Research local projects where humans are changing the environment to ensure a species' survival.	• Brainstorm and sketch things in the home that are designed to help humans survive, e.g., heater for warmth, stove to cook. (T/E 2.1, 2.2)
Energy and Living Things	11. Describe how energy derived from the sun is used by plants to produce sugars (photosynthesis) and is transferred within a food chain from producers (plants) to consumers to decomposers.	• Make a food chain. Begin with the sun as the source of energy and end with decomposers. Create links that show the relationship of plants and animals in the chain. Show the direction of the flow of energy. Discuss results if various links in the chain are broken.	• Design and build a compost bin. Use a thermometer to measure the temperature rise during composting. Discuss where heat (energy) comes from (decomposers metabolize energy stored by producers and consumers). (T/E 1.2)

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences
Grades 6-8		**Life Science**
Classification of Organisms	1. Classify organisms into the currently recognized kingdoms according to characteristics that they share. Be familiar with organisms from each kingdom.	
Structure and Function of Cells	2. Recognize that all organisms are composed of cells, and that many organisms are single-celled (unicellular), e.g., bacteria, yeast. In these single-celled organisms, one cell must carry out all of the basic functions of life.	• Observe, describe, record, and compare a variety of unicellular organisms found in aquatic ecosystems.
	3. Compare and contrast plant and animal cells, including major organelles (cell membrane, cell wall, nucleus, cytoplasm, chloroplasts, mitochondria, vacuoles).	• Observe a range of plant and animal cells to identify the cell wall, cell membrane, chloroplasts, vacuoles, nucleus, and cytoplasm when present.
	4. Recognize that within cells, many of the basic functions of organisms (e.g., extracting energy from food and getting rid of waste) are carried out. The way in which cells function is similar in all living organisms.	
Systems in Living Things	5. Describe the hierarchical organization of multicellular organisms from cells to tissues to organs to systems to organisms.	
	6. Identify the general functions of the major systems of the human body (digestion, respiration, reproduction, circulation, excretion, protection from disease, and movement, control, and coordination) and describe ways that these systems interact with each other.	
Reproduction and Heredity	7. Recognize that every organism requires a set of instructions that specifies its traits. These instructions are stored in the organism's	

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences
Grades 6-8		**Life Science**
	chromosomes. Heredity is the passage of these instructions from one generation to another.	
	8. Recognize that hereditary information is contained in genes located in the chromosomes of each cell. A human cell contains about 30,000 different genes on 23 different chromosomes.	
	9. Compare sexual reproduction (offspring inherit half of their genes from each parent) with asexual reproduction (offspring is an identical copy of the parent's cell).	
Evolution and Biodiversity	***10. Give examples of ways in which genetic variation and environmental factors are causes of evolution and the diversity of organisms.***	

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences
Grades 6-8		**Life Science**
Evolution and Biodiversity (cont.)	11. Recognize that evidence drawn from geology, fossils, and comparative anatomy provide the basis of the theory of evolution.	• Is the pterodactyl a flying reptile or the ancestor of birds? Discuss both possibilities based on the structural characteristics shown in pterodactyl fossils and those of modern birds and reptiles.
	12. Relate the extinction of species to a mismatch of adaptation and the environment.	• Relate how numerous species could not adapt to habitat destruction and overkilling by humans, e.g., woolly mammoth, passenger pigeon, great auk.
Living Things and Their Environment	13. Give examples of ways in which organisms interact and have different functions within an ecosystem that enable the ecosystem to survive.	• Study several symbiotic relationships such as oxpecker (bird) with rhinoceros (mammal). Identify specific benefits received by one or both partners.
Energy and Living Things	14. Explain the roles and relationships among producers, consumers, and decomposers in the process of energy transfer in a food web.	• Distribute pictures of various producers, consumers, and decomposers to groups of students. Have each group organize the pictures according to the relationships among the pictured species and write a paragraph that explains the roles and relationships.
	15. Explain how dead plants and animals are broken down by other living organisms and how this process contributes to the system as a whole.	• Observe decomposer organisms in a compost heap on the school grounds, a compost column in a plastic bottle, or a worm bin. Use compost for starting seeds in the classroom or in a schoolyard garden.
	16. Recognize that producers (plants that contain chlorophyll) use the energy from sunlight to make sugars from carbon dioxide and water through a process called photosynthesis. This food can be used immediately, stored for later use, or used by other organisms.	• Test for sugars and starch in plant leaves.
Changes in Ecosystems Over Time	17. Identify ways in which ecosystems have changed throughout geologic time in response to physical conditions, interactions among organisms, and the	• Study changes in an area of the schoolyard or a local ecosystem over an extended period. Students might even compare their observations to those made by

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences
Grades 6-8		**Life Science**
	actions of humans. Describe how changes may be catastrophes such as volcanic eruptions or ice storms.	students in previous years.
	18. Recognize that biological evolution accounts for the diversity of species developed through gradual processes over many generations.	

What It Looks Like in the Classroom

Organisms in Their Environments

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

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

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

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

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

Assessment Strategies

- Clearly state your expectations for the students’ work. Outline the expectations for how the field guide data should be organized and recorded. It is helpful to have a sample of the level of work expected, such as a high quality field guide developed by previous students.

- Develop a rubric that assesses how accurately the student identifies, classifies, catalogs, and places the organisms in a food web.
- As a culminating activity, invite parents and friends to school and ask students to present their findings. The teacher may wish to ask a community member to help evaluate the students' presentations.

Science Learning Standards

1. Classify plants and animals according to the physical characteristics that they share.

3. Recognize that plants and animals go through predictable life cycles that include birth, growth, development, reproduction, and death.

Biology Learning Standards for a Full First-Year Course in Grade 9 or 10

1. The Chemistry of Life

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

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

2. Structure and Function of Cells

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

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

3. Genetics

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

3.1 Describe the structure and function of DNA, and distinguish among replication, transcription, and translation. *
3.2 Describe the processes of replication, transcription, and translation and how they relate to each other in molecular biology.
3.3 Describe the general pathway by which ribosomes synthesize proteins by using tRNAs to translate genetic information encoded in mRNAs.
3.4 Explain how mutations in the DNA sequence of a gene may be silent or result in phenotypic change in an organism and in its offspring.
3.5 Differentiate between dominant, recessive, codominant, polygenic, and sex-linked traits.
3.6 State Mendel’s laws of segregation and independent assortment.
3.7 Use a Punnett Square to determine the genotype and phenotype of monohybrid crosses. *
3.8 Explain how zygotes are produced in the fertilization process.
3.9 Recognize that while viruses lack cellular structure, they have the genetic material to invade living cells.

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

4. Human Anatomy and Physiology

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

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

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

5. Evolution and Biodiversity

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

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

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

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

6. Ecology

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

6.1 Explain how biotic and abiotic factors cycle in an ecosystem (water, carbon, oxygen, and nitrogen). *

6.2 Use a food web to identify and distinguish producers, consumers, and decomposers, and explain the transfer of energy through trophic levels. *

6.3 Identify the factors in an ecosystem that influence fluctuations in population size.

6.4 Analyze changes in an ecosystem resulting from natural causes, changes in climate, human activity, or introduction of non-native species.

6.5 Explain how symbiotic behavior produces interactions within ecosystems.

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

Strand 3: Physical Sciences (Chemistry and Physics)

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

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

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

The physical science learning standards for PreK-2 fall under the topics of *Observable Properties of Objects, States of Matter,* and *Position and Motion of Objects.* Young children's curiosity is engaged when they observe physical processes and sort objects by different criteria. During these activities, children learn basic concepts about how things are alike or different. As they push, pull, and transform objects by acting upon them, children see the results of their actions and begin to understand how part of their world works. They continue to build understanding by telling stories about what they did and what they found out.

The standards for grades 3-5 fall under the topics of *Properties of Objects and Materials, States of Matter*, and *Forms of Energy* (including electrical, magnetic, sound, and light). Students' growth in their understanding of ordinary things allows them to make the intellectual connections necessary for understanding how the physical world works. Students are able to design simple comparative tests, carry out the tests, collect and record data, analyze results, and communicate their findings to others.

The standards for grades 6-8 fall under the topics of *Properties of Matter*, *Elements, Compounds and Mixtures*, *Motion of Objects*, *Forms of Energy,* and *Heat Energy*. While students at the middle school level may be better able to manage and represent ideas through language and mathematics, they still need concrete, physical-world experiences to help them develop concepts associated with motion, mass, volume, and energy. As they learn to make accurate measurements using a variety of instruments, their experiments become more quantitative and their physical models more precise. Students are able to understand relationships and can graph one measurement in relation to another, such as temperature change over time. Students may collect data by using microcomputer- or calculator-based laboratories (MBL or CBL), and learn to make sense immediately of graphical and other abstract representations essential to scientific understanding.

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

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

Physical Sciences (Chemistry and Physics)

Please note: The technology/engineering standards for grades PreK-5 are on page 55.

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences	Suggested Extensions to Learning in Technology/Engineering
Grades PreK-2			**Physical Sciences**
Observable Properties of Objects	1. Sort objects by observable properties such as size, shape, color, weight, and texture.	• Manipulate, observe, compare, describe, and group objects found in the classroom, on the playground, and at home.	• Predict from looking at the shape of a simple tool or object what things it might be used for, e.g., pliers, letter opener, paperweight. (T/E 1.2, 2.1)
States of Matter	2. Identify objects and materials as solid, liquid, or gas. Recognize that solids have a definite shape and that liquids and gases take the shape of their container.	• Using transparent containers of very different shapes (e.g., cylinder, cone, cube) pour water from one container into another. Observe and discuss the “changing shape” of the water.	• Ask students to bring in different types of containers from home. Discuss and demonstrate whether the containers are appropriate to hold solids and liquids, e.g., an unwaxed cardboard box will absorb water and eventually disintegrate while a glass bottle will not. (T/E 1.1, 1.2)
Position and Motion of Objects	3. Describe the various ways that objects can move, such as in a straight line, zigzag, back-and-forth, round-and-round, fast, and slow.	• Use a spinning toy (e.g., a top) and a rocking toy (e.g., a rocking horse) to explore round-and-round motion and back-and-forth motion.	• Using construction paper and glue, design a three-dimensional object that will roll in a straight line and a three-dimensional object that will roll around in a circle. (T/E 1.3, 2.1)

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences	Suggested Extensions to Learning in Technology/Engineering
Grades PreK-2			**Physical Sciences**
	4. Demonstrate that the way to change the motion of an object is to apply a force (give it a push or a pull). The greater the force, the greater the change in the motion of the object.	• Observe objects as you push and pull them on a hard, smooth surface. Make predictions as to what direction they will move and how far they will go. Repeat using various surfaces, e.g., rough, soft, etc.	•

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences	Suggested Extensions to Learning in Technology/Engineering
Grades PreK-2			**Physical Sciences**
	5. Recognize that under some conditions, objects can be balanced.	• Try to make a long thin rectangular block of wood stand upright on each face. Note that it stands (balances) very easily on some faces, but not on all.	• Design a lever, putting unequal weights on the ends of the balance board. Observe. Now find ways to restore the balance by moving the fulcrum, keeping each weight in the same place. Discuss what happens. (T/E 2.1)

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences	Suggested Extensions to Learning in Technology/Engineering
Grades 3-5			**Physical Sciences**
Properties of Objects and Materials	1. Differentiate between properties of objects (e.g., size, shape, weight) and properties of materials (e.g., color, texture, hardness).	• Gather a variety of solid objects. Collect data on properties of these objects such as origin (manmade or natural), weight (heavy, medium, light), length, odor, color, hardness, and flexibility. • Use a variety of objects. Identify at least the main material the object is made of, e.g., wood, metal, paper, pottery/ceramic, plastic, glass. Discuss the function of the object and its parts. Discuss how the properties of the materials used are suited to the function of the overall object or some part of it.	• Observe several common objects, discuss the different materials that they are made of, and the reasons that those specific materials may have been used. (T/E 1.1) • Given a variety of objects made of different materials, ask questions and make predictions about their hardness, flexibility, and strength. Test to see if your predictions were correct. (T/E 1.1)
States of Matter	2. Compare and contrast solids, liquids, and gases based on the basic properties of each of these states of matter.	• Design several stations, each of which demonstrates a state of matter, e.g., water table, balloon and fan table, sand and block table, etc.	• Design one container for each of the states of matter, taking into account what material properties are important, e.g., size, shape, flexibility. (T/E 1.1, 2.3)
	3. Describe how water can be changed from one state to another by adding or taking away heat.	• Do simple investigations with evaporation, condensation, freezing, and melting. Confirm that water expands upon freezing.	• Using given insulating materials, try to keep an ice cube from melting. (T/E 1.1)

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences	Suggested Extensions to Learning in Technology/Engineering
Grades 3-5			**Physical Sciences**
Forms of Energy	4. Identify the basic forms of energy (light, sound, heat, electrical, and magnetic). Recognize that energy is the ability to cause motion or create change.	• Play music through a speaker with and without a grill cover. Discuss the difference in sound.	• Design and construct a candle wheel that demonstrates how heat can cause a propeller to spin (a very popular craft toy). (T/E 1.1, 1.2, 2.2, 2.3)
	5. Give examples of how energy can be transferred from one form to another.	• Rub two pieces of wood together (mechanical energy) and observe the change in temperature of the wood.	• Design and build a simple roller coaster for a marble or toy car to demonstrate how energy changes from one form to another. (T/E 2.2, 2.3)

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences	Suggested Extensions to Learning in Technology/Engineering
Grades 3-5			**Physical Sciences**
Electrical Energy	6. Recognize that electricity in circuits requires a complete loop through which an electrical current can pass, and that electricity can produce light, heat, and sound.		• Using graphic symbols, draw and label a simple electric circuit. (T/E 2.2) • Using batteries, bulbs, and wires, build a series circuit. (T/E 1.2, 2.2) • Design and build a simple game using simple circuits. (T/E 1.2, 2.2)
	7. Identify and classify objects and materials that conduct electricity and objects and materials that are insulators of electricity.	• Provide a collection of materials that are good conductors and good insulators. Have students determine each material's electrical conductivity by testing the materials with a simple battery/bulb circuit.	• Select from a variety of materials (e.g., cloth, cardboard, Styrofoam, plastic, etc.) to design and construct a simple device (prototype) that could be used as an insulator. Do a simple test of its effectiveness. (T/E 1.1, 1.2, 2.2, 2.3)
	8. Explain how electromagnets can be made, and give examples of how they can be used.		• Design and construct a simple game or toy (prototype) that works because of electromagnets. (T/E 1.1, 1.2, 2.2, 2.3) • Make an electromagnet with a six-volt battery, insulated wire, and a large nail. (T/E 1.2, 2.1, 2.2, 2.3)

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences	Suggested Extensions to Learning in Technology/Engineering
Grades 3-5			**Physical Sciences**
Magnetic Energy	9. Recognize that magnets have poles that repel and attract each other.	• Balance ring magnets on a pencil. Note: The shape of a ring magnet obscures the locations of its poles. • Provide sealed field detectors (iron filings confined between sheets of plastic or iron filings sealed in oil). Use to show and draw magnetic fields in two and three dimensions.	• Design and build a magnetic device to sort steel from aluminum materials for recycling. (T/E 1.1)
Magnetic Energy (cont.)	10. Identify and classify objects and materials that a magnet will attract and objects and materials that a magnet will not attract.	• Test a variety of materials with assorted magnets. Include samples of pure iron and magnetic steel. Include samples of non-magnetic metals. Mention the two other magnetic metals: pure cobalt and pure nickel. Test a U.S. five-cent coin. Is a U.S. nickel coin made of pure nickel?	• Design and construct a device that utilizes magnets to lift a metal weight at least six inches off the ground. (T/E 1.1, 1.3, 2.3)
Sound Energy	11. Recognize that sound is produced by vibrating objects and requires a medium through which to travel. Relate the rate of vibration to the pitch of the sound.	• Use tuning forks to demonstrate the relationship between vibration and sound.	• Design and construct a telephone (prototype) using a variety of materials, e.g., paper cups, string, tin cans, and wire. Determine which prototype works best. Discuss possible reasons. (T/E 1.1, 1.2, 2.2, 2.3)
Light Energy	12. Recognize that light travels in a straight line until it strikes an object or travels from one medium to another, and that light can be reflected, refracted, and absorbed.	• Use a flashlight, mirrors, and water to demonstrate reflection and refraction.	• Design and build a prototype to inhibit solar heating of a car, e.g., windshield reflector, window tinting. (T/E 1.2, 2.1, 2.3)

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences	Suggested Extensions to Learning in Technology/Engineering
Grades 3-5			**Physical Sciences**
			• Design and build a pinhole camera. Test the effects of light on light sensitive paper. (T/E 1.2, 2.3) • Design and build a periscope from cardboard and mirrors. (T/E 1.1, 1.2, 2.3)

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences
Grades 6-8		**Physical Sciences**
Properties of Matter	1. Differentiate between weight and mass, recognizing that weight is the amount of gravitational pull on an object.	• Explain how to determine the weight of a dense object in air and in water. Next carry out your plan. Explain how the results you obtain are related to the different definitions of mass and weight.
	2. Differentiate between volume and mass. Define density.	
	3. Recognize that the measurement of volume and mass requires understanding of the sensitivity of measurement tools (e.g., rulers, graduated cylinders, balances) and knowledge and appropriate use of significant digits.	• Calculate the volumes of regular objects from linear measurements. Measure the volumes of the same objects by displacement of water. Use the metric system. Discuss the accuracy limits of your procedures and how they explain any observed differences between your calculated volumes and your measured volumes. • Use measurements of weight and volume to find out if several solid metal objects are made of the same metal or different metals. Explain why some of your conclusions may be more definite than others. Give reasons based on accuracy of measurements and on the physical properties of metals, where applicable.
	4. Explain and give examples of how mass is conserved in a closed system.	• Melt, dissolve, and precipitate various substances to observe examples of the conservation of mass. • Carry out a chemical reaction. Determine the masses of all reactants and all products. Discuss whether results support the conservation of mass, taking into account the sensitivity and accuracy of measuring equipment used.
Elements, Compounds, and Mixtures	5. Recognize that there are more than 100 elements that combine in a multitude of ways to produce compounds that make up all of the living and nonliving things that we encounter.	• Demonstrate with atomic models (e.g., ball and stick) how atoms can combine in a large number of ways. Explain why the number of combinations is large, but still limited. Also use the models to demonstrate the

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences
Grades 6-8		**Physical Sciences**
		conservation of mass in the chemical reactions you are modeling.
	6. Differentiate between an atom (the smallest unit of an element that maintains the characteristics of that element) and a molecule (the smallest unit of a compound that maintains the characteristics of that compound).	• Use atomic models (or Lego blocks, assigning colors to various atoms) to build molecules of water, sodium chloride, carbon dioxide, ammonia, etc.

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences
Grades 6-8		**Physical Sciences**
	7. Give basic examples of elements and compounds.	• Heat sugar in a crucible with an inverted funnel over it. Observe carbon residue and water vapor in the funnel as evidence of the breakdown of components. Continue heating the carbon residue to show that carbon residue does not decompose. Safety note: sugar melts at a very high temperature and can cause serious burns.
	8. Differentiate between mixtures and pure substances.	
	9. Recognize that a substance (element or compound) has a melting point and a boiling point, both of which are independent of the amount of the sample.	
	10. Differentiate between physical changes and chemical changes.	• Demonstrate with molecular ball-and-stick models the physical change that converts liquid water into ice. Also demonstrate with molecular ball-and-stick models the chemical change that converts hydrogen peroxide into water and oxygen gas.
Motion of Objects	11. Explain and give examples of how the motion of an object can be described by its position, direction of motion, and speed.	
	12. Graph and interpret distance vs. time graphs for constant speed.	
Forms of Energy	13. Differentiate between potential and kinetic energy. Identify situations where kinetic energy is transformed into potential energy and vice versa.	
Heat Energy	14. Recognize that heat is a form of energy and that temperature change results from adding or taking away heat from a system.	
	15. Explain the effect of heat on particle motion	

Topic	Learning Standard	Ideas for Developing Investigations and Learning Experiences
	through a description of what happens to particles during a change in phase.	
	16. Give examples of how heat moves in predictable ways, moving from warmer objects to cooler ones until they reach equilibrium.	• Place a thermometer in a ball of clay and place this in an insulated cup filled with hot water. Record the temperature every minute. Then remove the thermometer and ball of clay and place them in an insulated cup of cold water that contains a second thermometer. Observe and record the changes in temperature on both thermometers. Explain the observations in terms of heat flow. Include direction of heat flow and why it stops.

Chemistry Learning Standards for a Full First-Year Course in Grade 10 or 11

1. Properties of Matter

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

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

1.2 Explain the difference between mixtures and pure substances. *

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

1.4 Distinguish between chemical and physical changes.

2. Atomic Structure

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

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

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

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

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

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

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

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

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

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

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

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

3. Periodicity

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

3.1 Explain the relationship of an element's position on the periodic table to its atomic number and mass. *

3.2 Use the periodic table to identify metals, nonmetals, metalloids, families (groups), periods, valence electrons, and reactivity with other elements in the table.

3.3 Relate the position of an element on the periodic table to its electron configuration.

3.4 Identify trends on the periodic table (ionization energy, electronegativity, electron affinity, and relative size of atoms and ions).

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

4. Chemical Bonding

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

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

4.2 Draw Lewis dot structures for simple molecules.

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

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

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

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

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

5. Chemical Reactions and Stoichiometry

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

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

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

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

5.4 Determine molar mass, percent compositions, empirical formulas, and molecular formulas.

5.5 Calculate mass-mass, mass-volume, volume-volume, and limiting reactant problems for chemical reactions.

5.6 Calculate percent yield in a chemical reaction.

6. Gases and Kinetic Molecular Theory

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

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

6.2 Explain the relationship between temperature and average kinetic energy.

6.3 Perform calculations using the ideal gas law.

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

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

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

7. Solutions

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

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

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

7.3 Describe the dynamic equilibrium that occurs in saturated solutions.

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

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

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

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

8. Acids and Bases

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

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

8.2 Compare and contrast the nature, behavior, concentration and strength of acids and bases.

- **a. Acid-base neutralization**
- **b. Degree of dissociation or ionization**
- **c. Electrical conductivity**

8.3 Identify a buffer and explain how it works.

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

8.4 Explain how indicators are used in titrations and how they are selected.

8.5 Describe an acid-base titration. Identify when the equivalence point is reached and its significance.

8.6 Calculate the pH or pOH of aqueous solutions using the hydronium or hydroxide ion concentration.

9. Equilibrium and Kinetics

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

9.1 Write the equilibrium expression and calculate the equilibrium constant for a reaction.

9.2 Predict the shift in equilibrium when the system is subjected to a stress (LeChatelier's principle).

9.3 Identify the factors that affect the rate of a chemical reaction (temperature, concentration) and the factors that can cause a shift in equilibrium (concentration, pressure, volume, temperature).

9.4 Explain rates of reaction in terms of collision frequency, energy of collisions, and orientation of colliding molecules.

9.5 Define the role of activation energy in a chemical reaction.

10. Thermochemistry (Enthalpy)

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

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

11. Oxidation-Reduction and Electrochemistry
Broad Concept: Oxidation-reduction reactions occur by electron transfer and constitute a major class of chemical reactions. Examples of redox reactions occur everywhere; their consequences are experienced daily.
11.1 Describe the chemical processes known as oxidation and reduction.
11.2 Assign oxidation numbers.
11.3 Balance oxidation-reduction equations by using half-reactions.
11.4 Identify the components, and describe the processes that occur in an electrochemical cell.
11.5 Explain how a typical battery, such as a lead storage battery or a dry cell, works.
11.6 Compare and contrast voltaic and electrolytic cells and their uses.
11.7 Calculate the net voltage of a cell given a table of standard reduction potentials.

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

Physics Learning Standards for a Full First-Year Course in Grade 9 or 10

1. Motion and Forces

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

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

2. Conservation of Energy and Momentum

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

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

3. Heat and Heat Transfer

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

3.1 Relate thermal energy to molecular motion. *
3.2 Differentiate between specific heat and heat capacity.
3.3 Explain the relationship among temperature change in a substance for a given amount of heat transferred, the amount (mass) of the substance, and the specific heat of the substance.

3.4 Recognize that matter exists in four phases, and explain what happens during a phase change.

4. Waves

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

4.1 Differentiate between wave motion (simple harmonic nonlinear motion) and the motion of objects (nonharmonic). *

4.2 Recognize the measurable properties of waves (e.g., velocity, frequency, wavelength) and explain the relationships among them. *

4.3 Distinguish between transverse and longitudinal waves.

4.4 Distinguish between mechanical and electromagnetic waves. *

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

4.5 Interpret and be able to apply the laws of reflection and refraction (qualitatively) to all waves.
4.6 Recognize the effects of polarization, wave interaction, and the Doppler effect.
4.7 Explain, graph, and interpret graphs of constructive and destructive interference of waves.
4.8 Explain the relationship between the speed of a wave (e.g., sound) and the medium it travels through.
4.9 Recognize the characteristics of a standing wave and explain the conditions under which two waves on a string or in a pipe can interfere to produce a standing wave.

5. Electromagnetism

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

5.1 Recognize the characteristics of static charge, and explain how a static charge is generated.
5.2 Interpret and apply Coulomb's law.
5.3 Explain the difference in concept between electric forces and electric fields.
5.4 Develop a qualitative and quantitative understanding of current, voltage, resistance, and the connection between them.
5.5 Identify appropriate units of measurement for current, voltage, and resistance, and explain how they are measured.
5.6 Analyze circuits (find the current at any point and the potential difference between any two points in the circuit) using Kirchoff's and Ohm's laws.

6. Electromagnetic Radiation
Broad Concept: Oscillating electric or magnetic fields can generate electromagnetic waves over a wide spectrum of energies.
6.1 Describe the electromagnetic spectrum in terms of wavelength and energy, and be able to identify specific regions such as visible light. *
6.2 Explain how the various wavelengths in the electromagnetic spectrum have many useful applications such as radio, television, microwave appliances, and cellular telephones.
6.3 Calculate the frequency and energy of an electromagnetic wave from the wavelength.
6.4 Recognize and explain the ways in which the direction of visible light can be changed.

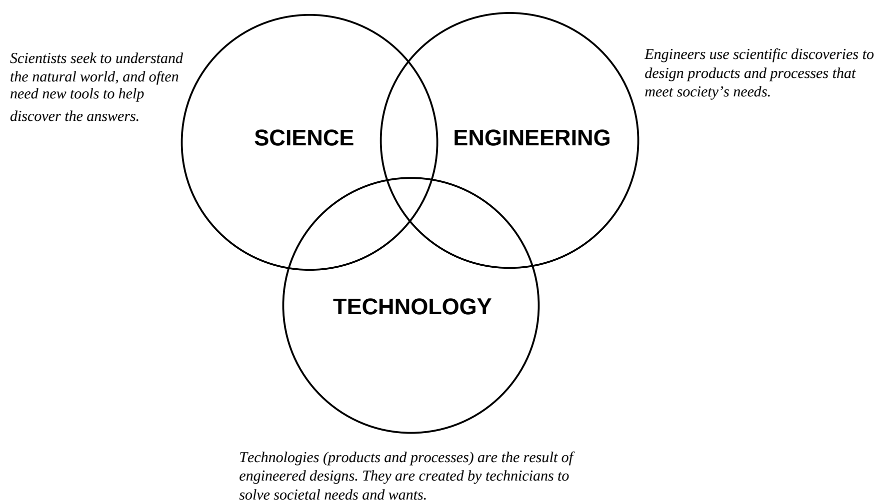
Boldface type indicates core standards for full-year courses. An asterisk (*) indicates core standards for integrated courses.

Strand 4: Technology/Engineering

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

Technology/engineering works in conjunction with science to expand our capacity to understand the world. For example, scientists and engineers apply scientific knowledge of light to develop lasers and fiber optic technologies and other technologies in medical imaging. They also apply this scientific knowledge to develop such modern communications technologies as telephones, fax machines, and electronic mail.

The Relationship Among Science, Engineering, and Technology



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

Technologies developed through engineering include the systems that provide our houses with water and heat; roads, bridges, tunnels, and the cars that we drive; airplanes and spacecraft; cellular phones, televisions, and computers; many of today’s children’s toys; and systems that create special effects in movies. Each of these came about as the result of recognizing a need or problem and creating a technological solution. Figure 1 on page 53 shows the steps of the engineering design process. Beginning in the early grades and continuing through high school, students carry out this design process in ever more sophisticated ways. As they gain more experience and knowledge, they are able to draw on other disciplines, especially mathematics and science, to understand and solve problems.

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

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

In grades 6-8, students pursue engineering questions and technological solutions that emphasize research and problem solving. They identify and understand the five elements of a technology system (goal, inputs, processes, outputs, and feedback). They acquire basic skills in the safe use of hand tools, power tools, and machines. They explore engineering design; materials, tools, and machines; and communication, manufacturing, construction, transportation, and bioengineering technologies. Starting in these grades and extending through grade 10, the topics of power and energy are incorporated into the study of most areas of technology. Students integrate knowledge they acquired in their mathematics and science curricula to understand the links to engineering. They achieve a more advanced level of skill in engineering design by learning to conceptualize a problem, design prototypes in three dimensions, and use hand and power tools to construct their prototypes, test their prototypes, and make modifications as necessary. The culmination of the engineering design experience is the development and delivery of an engineering presentation.

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

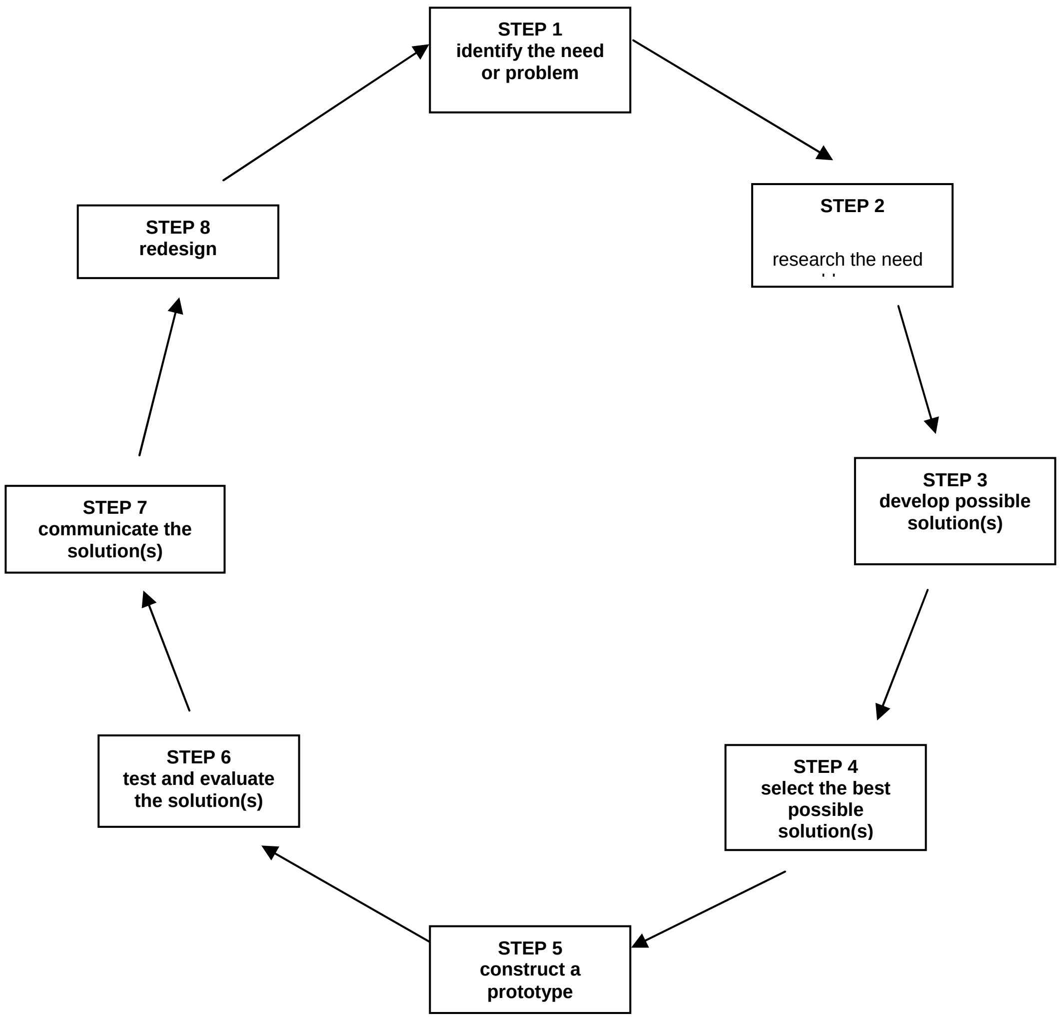
Technology/engineering curricula in grades 11 and 12 follow the approaches used for the previous two grades but expand in a variety of areas based on available school expertise and student interest. Students may explore advanced technology/engineering curricula such as automation and robotics, multimedia,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

- expanding their studies in the area of engineering and technology because they are interested in a college-level engineering program,

- pursuing career pathways in relevant technology fields, or
- learning about certain areas of technology/engineering to expand their general educational background, but who will not necessarily follow a technical career.

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

Figure 1
Steps of the Engineering Design Process



1. Identify the need or problem
2. Research the need or problem
   - Examine current state of the issue and current solutions
   - Explore other options via the internet, library, interviews, etc.
3. Develop possible solution(s)
   - Brainstorm possible solutions
   - Draw on mathematics and science
   - Articulate the possible solutions in two and three dimensions
   - Refine the possible solutions
4. Select the best possible solution(s)
   - Determine which solution(s) best meet(s) the original requirements
5. Construct a prototype
   - Model the selected solution(s) in two and three dimensions

6. Test and evaluate the solution(s)
    - Does it work?
    - Does it meet the original design constraints?
7. Communicate the solution(s)
    - Make an engineering presentation that includes a discussion of how the solution(s) best meet(s) the needs of the initial problem, opportunity, or need
    - Discuss societal impact and tradeoffs of the solution(s)
8. Redesign
    - Overhaul the solution(s) based on information gathered during the tests and presentation

Technology/Engineering Learning Standards

Please note: Suggested extensions to learning in technology/engineering for grades PreK-5 are listed with the science learning standards. See pages 12-21 (earth and space science), 31-38 (life science), and 46-51 (physical sciences).

Grades PreK-2

1. Materials and Tools

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

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

2. Engineering Design

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

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

Grades 3-5

1. Materials and Tools

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

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

2. Engineering Design

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

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

Grades 6-8

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

1. Materials, Tools, and Machines

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

1.1 Given a design task, identify appropriate materials (e.g., wood, paper, plastic, aggregates, ceramics, metals, solvents, adhesives) based on specific properties and characteristics (e.g., weight, strength, hardness, and flexibility).

1.2 Identify and explain appropriate measuring tools, hand tools, and power tools used to hold, lift, carry, fasten, and separate, and explain their safe and proper use.

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

Suggested Learning Activities

- Conduct tests for weight, strength, hardness, and flexibility of various materials, e.g., wood, paper, plastic, ceramics, metals. (1.1)
- Design and build a catapult that will toss a marshmallow the farthest. (1.1, 1.2, 1.3)
- Use a variety of hand tools and machines to change materials into new forms through forming, separating, and combining processes, and processes that cause internal change to occur. (1.2)

2. Engineering Design

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

2.1 Identify and explain the steps of the engineering design process, i.e., identify the need or problem, research the problem, develop possible solutions, select the best possible solution(s), construct a prototype, test and evaluate, communicate the solution(s), and redesign.

2.2 Demonstrate methods of representing solutions to a design problem, e.g., sketches, orthographic projections, multiview drawings.

2.3 Describe and explain the purpose of a given prototype.

2.4 Identify appropriate materials, tools, and machines needed to construct a prototype of a given engineering design.

2.5 Explain how such design features as size, shape, weight, function, and cost limitations would affect the construction of a given prototype.

2.6 Identify the five elements of a universal systems model: goal, inputs, processes, outputs, and feedback.

Suggested Learning Activities

- Given a prototype, design a test to evaluate whether it meets the design specifications. (2.1)

- Using test results, modify the prototype to optimize the solution, i.e., bring the design closer to meeting the design constraints. (2.1)
- Communicate the results of an engineering design through a coherent written, oral, or visual presentation. (2.1)
- Develop plans, including drawings with measurements and details of construction, and construct a model of the solution, exhibiting a degree of craftsmanship. (2.2)

3. Communication Technologies

Broad Concept: Ideas can be communicated though engineering drawings, written reports, and pictures.

3.1 Identify and explain the components of a communication system, i.e., source, encoder, transmitter, receiver, decoder, storage, retrieval, and destination.

3.2 Identify and explain the appropriate tools, machines, and electronic devices (e.g., drawing tools, computer-aided design, and cameras) used to produce and/or reproduce design solutions (e.g., engineering drawings, prototypes, and reports).

3.3 Identify and compare communication technologies and systems, i.e., audio, visual, printed, and mass communication.

3.4 Identify and explain how symbols and icons (e.g., international symbols and graphics) are used to communicate a message.

4. Manufacturing Technologies

Broad Concept: Manufacturing is the process of converting raw materials (primary process) into physical goods (secondary process), involving multiple industrial processes, e.g., assembly, multiple stages of production, quality control.

4.1 Describe and explain the manufacturing systems of custom and mass production.

4.2 Explain and give examples of the impacts of interchangeable parts, components of mass-produced products, and the use of automation, e.g., robotics.

4.3 Describe a manufacturing organization, e.g., corporate structure, research and development, production, marketing, quality control, distribution.

4.4 Explain basic processes in manufacturing systems, e.g., cutting, shaping, assembling, joining, finishing, quality control, and safety.

5. Construction Technologies

Broad Concept: Construction technology involves building structures in order to contain, shelter, manufacture, transport, communicate, and provide recreation.

5.1 Describe and explain parts of a structure, e.g., foundation, flooring, decking, wall, roofing systems.

5.2 Identify and describe three major types of bridges (e.g., arch, beam, and suspension) and their appropriate uses (e.g., site, span, resources, and load).

5.3 Explain how the forces of tension, compression, torsion, bending, and shear affect the performance of bridges.

5.4 Describe and explain the effects of loads and structural shapes on bridges.

Suggested Learning Activities

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

6. Transportation Technologies

Broad Concept: Transportation technologies are systems and devices that move goods and people from one place to another across or through land, air, water, or space.

6.1 Identify and compare examples of transportation systems and devices that operate on each of the following: land, air, water, and space.

6.2 Given a transportation problem, explain a possible solution using the universal systems model.

6.3 Identify and describe three subsystems of a transportation vehicle or device, i.e., structural, propulsion, guidance, suspension, control, and support.

6.4 Identify and explain lift, drag, friction, thrust, and gravity in a vehicle or device, e.g., cars, boats, airplanes, rockets.

Suggested Learning Activities

- Design a model vehicle (with a safety belt restraint system and crush zones to absorb impact) to carry a raw egg as a passenger. (6.1)
- Design and construct a magnetic levitation vehicle as used in the monorail system. Discuss the vehicle's benefits and trade-offs. (6.2)
- Conduct a group discussion of the major technologies in transportation. Divide the class into small groups and discuss how the major technologies might affect future design of a transportation mode. After the group discussions, the students draw a design of a future transportation mode (car, bus, train, plane, etc.). The students present their vehicle design to the class, including a discussion of the subsystems used. (6.1, 6.3)

7. Bioengineering Technologies

Broad Concept: Bioengineering technologies explore the production of mechanical devices, products, biological substances, and organisms to improve health and/or contribute improvement to our daily lives.

7.1 Explain examples of adaptive or assistive devices, e.g., prosthetic devices, wheelchairs, eyeglasses, grab bars, hearing aids, lifts, braces.

7.2 Describe and explain adaptive and assistive bioengineered products, e.g., food, bio-fuels, irradiation, integrated pest management.

Suggested Learning Activities

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

Local Wonders

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

Technology/Engineering Grades 6-8

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

After building newspaper towers and talking about structures and foundations, fifth and sixth graders at the Watertown, Massachusetts Boys and Girls Club brainstormed a list of interesting structures in their town. They selected St. Patrick's, an elaborate church across the street from the clubhouse. The children brainstormed questions about their local wonder. Those with an engineering focus included: When was it built? How long did the construction take? Who built it? What is it made of? Why did the builders choose that material? What is underneath the building? What holds it up? What keeps it from falling down? How was it built? Were there any problems during construction and how were they solved? Questions with a social/environmental focus included: Why was it built? What did the area look like before it was built?

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

Students can use the following method to estimate the size of a large structure. First, measure a friend's height. Have your friend stand next to the structure, while you stand a distance away (across the street, for instance). Close one eye and use your fingers to "stack" your friend's height until you reach the top of the structure. Multiply the number of times you stacked your friend by his/her height to find the total estimated height of the structure.

The outline of the final report may look like this:

I. Name of group submitting report
II. Name and description of structure (identify the type of structure, e.g., bridge, skyscraper, and decribe and explain its parts)
III. Location
IV. Approximate date structure was completed
V. Approximate size
VI. Why we chose this particular local wonder
VII. What's important about our local wonder
VIII. Things we learned about our local wonder (include information such as type of construction, engineering design concepts, and forces acting on the structure)
IX. Interesting facts about our local wonder

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

Assessment Strategies

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

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

Engineering Design Learning Standards

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

Construction Technologies Learning Standards

5.1 Describe and explain parts of a structure, e.g., foundation, flooring, decking, wall, roofing systems.
5.2 Identify and describe three major types of bridges (e.g., arch, beam, and suspension) and their appropriate uses (e.g., site, span, resources, and load).

5.3 Explain how the forces of tension, compression, torsion, bending, and shear affect the performance of bridges.
5.4 Describe and explain the effects of loads and structural shapes on bridges.

Technology/Engineering Learning Standards for a Full First-Year Course in Grades 9 or 10

1. Engineering Design

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

1.1 Identify and explain the steps of the engineering design process, i.e., identify the problem, research the problem, develop possible solutions, select the best possible solution(s), construct a prototype, test and evaluate, communicate the solution(s), and redesign.

1.2 Demonstrate knowledge of pictorial and multi-view drawings (e.g., orthographic projection, isometric, oblique, perspective) using proper techniques.

1.3 Demonstrate the use of drafting techniques with paper and pencil or computer-aided design (CAD) systems when available.

1.4 Apply scale and proportion to drawings, e.g., ¼" = 1'0".

1.5 Interpret plans, diagrams, and working drawings in the construction of a prototype.

Suggested Learning Activities

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

2. Construction Technologies

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

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

2.2 Identify and explain the purposes of common tools and measurement devices used in construction, e.g., spirit level, transit, framing square, plumb bob, spring scale, tape measure, strain gauge, venturi meter, pitot tube.

2.3 Describe how structures are constructed using a variety of processes and procedures, e.g., welds, bolts, and rivets are used to assemble metal framing materials.

2.4 Identify and explain the engineering properties of materials used in structures, e.g., elasticity, plasticity, thermal conductivity, density.

2.5 Differentiate the factors that affect the design and building of structures, such as zoning laws, building codes, and professional standards.

2.6 Calculate quantitatively the resultant forces for live loads and dead loads.

Suggested Learning Activities

- Demonstrate the transmission of loads for buildings and other structures. (2.1, 2.2, 2.6)
- Construct a truss and analyze to determine whether the members are in tension, compression, shear, and/or torsion. (2.1, 2.3, 2.4, 2.5)
- Given several types of measuring tools and testing tools, give students a challenge and have them evaluate the effectiveness of a tool for the given challenge. (2.2)
- Construct and test geometric shapes to determine their structural advantages depending on how they are loaded. (2.3, 2.5, 2.6, 2.6)
- Using a chart from the state building code, students should be able to correctly use the stress strain relationship to calculate the floor joist size needed. (2.4, 2.6)

Boldface type indicates core standards for full-year courses.

- Design and conduct a test for building materials such as density, strength, thermal conductivity, specific heat, and moisture resistance. (2.4, 2.5)
- Calculate the live load for the second floor of a building and show how that load is distributed to the floor below. (2.5, 2.6, 2.6)
- Identify ways to protect a watershed, e.g., silt barriers, hay bales, maintenance of watershed areas. (2.5)

3. Energy and Power Technologies–Fluid Systems

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

3.1 Differentiate between open (e.g., irrigation, forced hot air system) and closed (e.g., forced hot water system, hydroponics) fluid systems and their components such as valves, controlling devices, and metering devices.

3.2 Identify and explain sources of resistance (e.g., 45^{o} elbow, 90^{o} elbow, type of pipes, changes in diameter) for water moving through a pipe.

3.3 Explain Bernoulli's Principle and its effect on practical applications, i.e., airfoil design, spoiler design, carburetor.

3.4 Differentiate between hydraulic and pneumatic systems and provide examples of appropriate applications of each as they relate to manufacturing and transportation systems.

3.5 Explain the relationship between velocity and cross-sectional areas in the movement of a fluid.

3.6 Solve problems related to hydrostatic pressure and depth in fluid systems.

Suggested Learning Activities

- Demonstrate how the selection of piping materials, pumps and other materials is based on hydrostatic effects. (3.1, 3.5, 3.6)
- Demonstrate how a hydraulic brake system operates in an automobile. (3.1, 3.5, 3.6)
- Design a private septic system with consideration to the type of soil in the leach field. (3.1, 3.4)
- Identify the elements of a public sewer system and a private septic system. (3.1, 3.4)
- Explain engineering control volume concepts as applied to a domestic water system. Does the amount of water entering a residence equal the amount of water leaving the residence? (3.5)
- Design an airfoil or spoiler to examine Bernoulli's Principle. (3.3)

- Create a hydraulic arm powered by pistons that is capable of moving in three dimensions. (3.4, 3.6)
- Have students do a simple calculation with velocity and cross-sectional pipe size. Velocity times cross sectional area is a constant. As the pipe size changes the velocity will have to change as well. For example, if the pipe changes from a 2-inch diameter to a 1-inch diameter, the velocity will have to quadruple. (3.5, 3.6)

4. Energy and Power Technologies–Thermal Systems
Broad Concept: Thermal systems involve transfer of energy through conduction, convection, and radiation, and are used to control the environment.
4.1 Differentiate among conduction, convection, and radiation in a thermal system, e.g., heating and cooling a house, cooking.
4.2 Give examples of how conduction, convection, and radiation are used in the selection of materials, e.g., home and vehicle thermostat designs, circuit breakers.
4.3 Identify the differences between open and closed thermal systems, e.g., humidity control systems, heating systems, cooling systems.
4.4 Explain how environmental conditions influence heating and cooling of buildings and automobiles.
4.5 Identify and explain the tools, controls, and properties of materials used in a thermal system, e.g., thermostats, R Values, thermal conductivity, temperature sensors.

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

5. Energy and Power Technologies–Electrical Systems
Broad Concept: Electrical systems generate, transfer, and distribute electricity.
5.1 Describe the different instruments that can be used to measure voltage, e.g., voltmeter, multimeter.
5.2 Identify and explain the components of a circuit including a source, conductor, load, and controllers (controllers are switches, relays, diodes, transistors, integrated circuits).
5.3 Explain the relationship between resistance, voltage, and current (Ohm's Law).

5.4 Determine the voltages and currents in a series circuit and a parallel circuit.
5.5 Explain how to measure voltage, resistance, and current in electrical systems.
5.6 Describe the differences between Alternating Current (AC) and Direct Current (DC).

Suggested Learning Activities

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

6. Communication Technologies

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

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

Suggested Learning Activities

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

Boldface type indicates core standards for full-year courses.

7. Manufacturing Technologies

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

7.1 Explain the manufacturing processes of casting and molding, forming, separating, conditioning, assembling, and finishing.

7.2 Differentiate the selection of tools and procedures used in the safe production of products in the manufacturing process, e.g., hand tools, power tools, computer-aided manufacturing, three-dimensional modeling.

7.3 Explain the process and the programming of robotic action utilizing three axes. (7.3)

Suggested Learning Activities

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

Boldface type indicates core standards for full-year courses.

A Look at Energy Efficient Homes

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

Technology/Engineering Grades 9-10

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

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

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

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

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

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

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

Assessment Strategies

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

Engineering Design Learning Standards

1.6 Identify and explain the steps of the engineering design process, i.e., identify the problem, research the problem, develop possible solutions, select the best possible solution(s), construct a prototype, test and evaluate, communicate the solution(s), and redesign.
1.7 Demonstrate knowledge of pictorial and multi-view drawings (e.g. orthographic projection, isometric, oblique, perspective) using proper techniques.
1.8 Demonstrate the use of drafting techniques with paper and pencil or computer-aided design (CAD) systems when available.
1.9 Apply scale and proportion to drawings, e.g., ¼” = 1’0”.
1.10 Interpret plans, diagrams, and working drawings in the construction of a prototype.

Construction Technologies Learning Standards

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

Energy and Power Technologies–Thermal Systems Learning Standards

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

Appendix I: Learning Standards by Grade Span, Grades PreK-8

Earth and Space Science	Life Science	Physical Sciences	Technology/Engineering
GRADES PreK-2			
• Recognize that water, rocks, soil, and living organisms are found on the earth's surface. • Understand that air is a mixture of gases that is all around us and that wind is moving air. • Describe the weather changes from day to day and over the seasons. • Recognize that the sun supplies heat and light to the earth and is necessary for life. • Identify some events around us that have repeating patterns, including the seasons of the year, day and night.	• Recognize that animals (including humans) and plants are living things that grow, reproduce, and need food, air, and water. • Differentiate between living and nonliving things. Group both living and nonliving things according to the characteristics that they share. • Recognize that plants and animals have life cycles, and that life cycles vary for different living things. • Describe ways in which many plants and animals closely resemble their parents in observed appearance. • Recognize that fossils provide us with information about living things that inhabited the earth years ago. • Recognize that people and other animals interact with the environment through their senses of sight, hearing, touch, smell, and taste. • Recognize changes in appearance that animals and	• Sort objects by observable properties such as size, shape, color, weight, and texture. • Identify objects and materials as solid, liquid, or gas. Recognize that solids have a definite shape and that liquids and gases take the shape of their container. • Describe the various ways that objects can move, such as in a straight line, zigzag, back-and-forth, round-and-round, fast, and slow. • Demonstrate that the way to change the motion of an object is to apply a force (give it a push or a pull). The greater the force, the greater the change in the motion of the object. • Recognize that under some conditions, objects can be balanced.	• Identify and describe characteristics of natural materials (e.g., wood, cotton, fur, wool) and human-made materials (e.g., plastic, Styrofoam). • Identify and explain some possible uses for natural materials (e.g., wood, cotton, fur, wool) and human-made materials (e.g., plastic, Styrofoam). • Identify and describe the safe and proper use of tools and materials (e.g., glue, scissors, tape, ruler, paper, toothpicks, straws, spools) to construct simple structures. • Identify tools and simple machines used for a specific purpose, e.g., ramp, wheel, pulley, lever. • Describe how human beings use parts of the body as tools (e.g., teeth for cutting, hands for grasping and catching), and compare their use with the ways in which animals use those parts of their

Earth and Space Science	Life Science	Physical Sciences	Technology/Engineering
	plants go through as the seasons change. • Identify the ways in which an organism's habitat provides for its basic needs (plants require air, water, nutrients, and light; animals require food, water, air, and shelter).		bodies.

Earth and Space Science	Life Science	Physical Sciences	Technology/Engineering
Grades 3-5			

Earth and Space Science	Life Science	Physical Sciences	Technology/Engineering
Grades 3-5			
• Give a simple explanation of what a mineral is and some examples, e.g., quartz, mica. • Identify the physical properties of minerals (hardness, color, luster, cleavage, and streak), and explain how minerals can be tested for these different physical properties. • Identify the three categories of rocks (metamorphic, igneous, and sedimentary) based on based on how they are formed, and explain the natural and physical processes that create these rocks. • Explain and give examples of the ways in which soil is formed (the weathering of rock by water and wind and from the decomposition of plant and animal remains). • Recognize and discuss the different properties of soil, including color, texture (size of particles), the ability to retain water, and the ability to support the growth of plants. • Explain how air temperature, moisture, wind speed and direction, and precipitation make up the weather in a particular place and time. • Distinguish among the various forms of precipitation (rain, snow, sleet, and hail)	• Classify plants and animals according to the physical characteristics that they share. • Identify the structures in plants (leaves, roots, flowers, stem, bark, wood) that are responsible for food production, support, water transport, reproduction, growth, and protection. • Recognize that plants and animals go through predictable life cycles that include birth, growth, development, reproduction, and death. • Describe the major stages that characterize the life cycle of the frog and butterfly as they go through metamorphosis. • Differentiate between observed characteristics of plants and animals that are fully inherited (e.g., color of flower, shape of leaves, color of eyes, number of appendages) and characteristics that are affected by the climate or environment (e.g., browning of leaves due to too much sun, language spoken). • Give examples of how inherited characteristics may change over time as adaptations to changes in the environment that enable	• Differentiate between properties of objects (e.g., size, shape, weight) and properties of materials (e.g., color, texture, hardness). • Compare and contrast solids, liquids, and gases based on the basic properties of each of these states of matter. • Describe how water can be changed from one state to another by adding or taking away heat. • Identify the basic forms of energy (light, sound, heat, electrical, and magnetic). Recognize that energy is the ability to cause motion or create change. • Give examples of how energy can be transferred from one form to another. • Recognize that electricity in circuits requires a complete loop through which an electrical current can pass, and that electricity can produce light, heat, and sound. • Identify and classify objects and materials that conduct electricity and objects and materials that are insulators of electricity. • Explain how electromagnets can be made, and give examples of how they can be	• Identify materials used to accomplish a design task based on a specific property, i.e. weight, strength, hardness, and flexibility. • Identify and explain the appropriate materials and tools (e.g., hammer, screwdriver, pliers, tape measure, screws, nails, and other mechanical fasteners) to construct a given prototype safely. • Identify and explain the difference between simple and complex machines, e.g., hand can opener that includes multiple gears, wheel, wedge gear, and lever. • Identify a problem that reflects the need for shelter, storage, or convenience. • Describe different ways in which a problem can be represented, e.g., sketches, diagrams, graphic organizers, and lists. • Identify relevant design features (e.g., size, shape, weight) for building a prototype of a solution to a given problem. • Compare natural systems with mechanical systems that are designed to serve similar purposes, e.g., a bird's wings as compared to an airplane's

Earth and Space Science	Life Science	Physical Sciences	Technology/Engineering
Grades 3-5			
• Describe how global patterns such as the jet stream and water currents influence local weather in measurable terms such as temperature, wind direction and speed, and precipitation. • Differentiate between weather and climate. • Describe how water on earth cycles in different forms and in different locations, including underground and in the atmosphere. • Give examples of how the cycling of water, both in and out of the atmosphere, has an effect on climate. • Give examples of how the surface of the earth changes due to slow processes such as erosion and weathering, and rapid processes such as landslides, volcanic eruptions, and earthquakes. • Recognize that the earth is part of a system called the "solar system" that includes the sun (a star), planets, and many moons. The earth is the third planet from the sun in our solar system. • Recognize that the earth revolves around (orbits) the sun in a year's time and that the earth rotates on its axis once approximately every 24	• Give examples of how change in the environment (e.g., drought, cold) have caused some plants and animals to die or move to new locations (migration). • Describe how organisms meet some of their needs in an environment by using behaviors (patterns of activities) in response to information (stimuli) received from the environment. Recognize that some animal behaviors are instinctive (e.g., turtles burying their eggs), and others are learned (e.g., humans building fires for warmth, chimpanzees learning how to use tools). • Recognize plant behaviors, such as the way seedlings' stems grow toward light and their roots grow downward in response to gravity. Recognize that many plants and animals can survive harsh environments because of seasonal behaviors, e.g., in winter, some trees shed leaves, some animals hibernate, and other animals migrate. • Give examples of how organisms can cause changes in their environment to ensure survival. Explain how some	• Recognize that sound is produced by vibrating objects and requires a medium through which to travel. Relate the rate of vibration to the pitch of the sound. • Recognize that light travels in a straight line until it strikes an object or travels from one medium to another, and that light can be reflected, refracted, and absorbed.	

Earth and Space Science	Life Science	Physical Sciences	Technology/Engineering
Grades 3-5			
• Describe the changes that occur in the observable shape of the moon over the course of a month.	• Describe how energy derived from the sun is used by plants to produce sugars (photosynthesis) and is transferred within a food chain from producers (plants) to consumers to decomposers.		

Earth and Space Science	Life Science	Physical Sciences	Technology/Engineering
Grades 6-8			

Earth and Space Science	Life Science	Physical Sciences	Technology/Engineering
Grades 6-8			
• Recognize, interpret, and be able to create models of the earth's common physical features in various mapping representations, including contour maps. • Describe the layers of the solid earth, including the lithosphere, the hot convecting mantle, and the dense metallic core. • Differentiate among radiation, conduction, and convection, the three mechanisms by which heat is transferred through the earth's system. • Explain the relationship among the energy provided by the sun, the global patterns of atmospheric movement, and the temperature differences among water, land, and atmosphere. • Describe how the movement of the earth's crustal plates causes both slow changes in the earth's surface (e.g., formation of mountains and ocean basins) and rapid ones (e.g., volcanic eruptions and earthquakes). • Describe and give examples of ways in which the earth's surface is built up and torn down by natural processes, including deposition of sediments, rock formation, erosion, and weathering.	• Classify organisms into the currently recognized kingdoms according to characteristics that they share. Be familiar with organisms from each kingdom. • Recognize that all organisms are composed of cells, and that many organisms are single-celled (unicellular), e.g., bacteria, yeast. In these single-celled organisms, one cell must carry out all of the basic functions of life. • Compare and contrast plant and animal cells, including major organelles (cell membrane, cell wall, nucleus, cytoplasm, chloroplasts, mitochondria, vacuoles). • Recognize that within cells, many of the basic functions of organisms (e.g., extracting energy from food and getting rid of waste) are carried out. The way in which cells function is similar in all living organisms. • Describe the hierarchical organization of multicellular organisms from cells to tissues to organs to systems to organisms.	• Differentiate between weight and mass, recognizing that weight is the amount of gravitational pull on an object. • Differentiate between volume and mass. Define density. • Recognize that the measurement of volume and mass requires understanding of the sensitivity of measurement tools (e.g., rulers, graduated cylinders, balances) and knowledge and appropriate use of significant digits. • Explain and give examples of how mass is conserved in a closed system. • Recognize that there are more than 100 elements that combine in a multitude of ways to produce compounds that make up all of the living and nonliving things that we encounter. • Differentiate between an atom (the smallest unit of an element that maintains the characteristics of that element) and a molecule (the smallest unit of a compound that maintains the characteristics of that compound). • Give basic examples of elements and compounds. • Differentiate between mixtures and pure substances.	• Identify and explain the steps of the engineering design process, i.e., identify the need or problem, research the problem, develop possible solutions, select the best possible solution(s), construct a prototype, test and evaluate, communicate the solution(s), and redesign. • Demonstrate methods of representing solutions to a design problem, e.g., sketches, orthographic projections, multiview drawings. • Describe and explain the purpose of a given prototype. • Identify appropriate materials, tools, and machines needed to construct a prototype of a given engineering design. • Explain how such design features as size, shape, weight, function, and cost limitations would affect the construction of a given prototype. • Identify the five elements of a universal systems model: goal, inputs, processes, outputs, and feedback. • Given a design task, identify appropriate materials (e.g., wood, paper, plastic, aggregates, ceramics, metals, solvents, adhesives) based on

Earth and Space Science	Life Science	Physical Sciences	Technology/Engineering
Grades 6-8			
• Explain and give examples of how physical evidence, such as fossils and surface features of glaciation, supports theories that the earth has evolved over geologic time. • Recognize that gravity is a force that pulls all things on and near the earth toward the center of the earth. Gravity plays a major role in the formation of the planets, stars, and solar system and in determining their motions. • Describe lunar and solar eclipses, the observed moon phases, and tides. Relate them to the relative positions of the earth, moon, and sun. • Compare and contrast properties and conditions of objects in the solar system (i.e., sun, planets, and moons) to those on Earth (e.g., gravitational force, distance from the sun, speed, movement, temperature, and atmospheric conditions). • Explain how the tilt of the earth and its revolution around the sun result in an uneven heating of the earth, which in turn causes the seasons. • Recognize that the universe contains many billions of galaxies, and that each galaxy contains many billions of stars.	• Identify the general functions of the major systems of the human body (digestion, respiration, reproduction, circulation, excretion, protection from disease, and movement, control, and coordination) and describe ways that these systems interact with each other. • Recognize that every organism requires a set of instructions that specifies its traits. These instructions are stored in the organism's chromosomes. Heredity is the passage of these instructions from one generation to another • . Recognize that hereditary information is contained in genes located in the chromosomes of each cell. A human cell contains about 30,000 different genes on 23 different chromosomes. • Compare sexual reproduction (offspring inherit half of their genes from each parent) with asexual reproduction (offspring is an identical copy of the parent's cell). • Give examples of ways in which genetic variation and environmental factors are causes of evolution and the diversity of organisms. • Recognize that evidence drawn from geology, fossils, and comparative anatomy provide the basis of the theory of evolution. • Relate the extinction of species to a mismatch of adaptation and the environment.	• Recognize that a substance (element or compound) has a melting point and a boiling point, both of which are independent of the amount of the sample. • Differentiate between physical changes and chemical changes. • Explain and give examples of how the motion of an object can be described by its position, direction of motion, and speed. • Graph and interpret distance vs. time graphs for constant speed. • Differentiate between potential and kinetic energy. Identify situations where kinetic energy is transformed into potential energy and vice versa. • Recognize that heat is a form of energy and that temperature change results from adding or taking away heat from a system. • Explain the effect of heat on particle motion through a description of what happens to particles during a change in phase. • Give examples of how heat moves in predictable ways, moving from warmer objects to cooler ones until they reach equilibrium.	• Identify and explain appropriate measuring tools, hand tools, and power tools used to hold, lift, carry, fasten, and separate, and explain their safe and proper use. • Identify and explain the safe and proper use of measuring tools, hand tools, and machines (e.g., band saw, drill press, sanders, hammer, screwdriver, pliers, tape measure, screws, nails, and other mechanical fasteners) needed to construct a prototype of an engineering design. • Identify and explain the components of a communication system, i.e., source, encoder, transmitter, receiver, decoder, storage, retrieval, and destination. • Identify and explain the appropriate tools, machines, and electronic devices (e.g., drawing tools, computer-aided design, and cameras) used to produce and/or reproduce design solutions (e.g., engineering drawings, prototypes, and reports). • Identify and compare communication technologies and systems, i.e., audio, visual, printed, and mass

Earth and Space Science	Life Science	Physical Sciences	Technology/Engineering
Grades 6-8			
	• Explain how dead plants and Give examples of ways in which organisms interact and have different functions within an ecosystem that enable the ecosystem to survive. • Explain the roles and relationships among producers, consumers, and decomposers in the process of energy transfer in a food web. • animals are broken down by other living organisms and how this process contributes to the system as a whole. • Recognize that producers (plants that contain chlorophyll) use the energy from sunlight to make sugars from carbon dioxide and water through a process called photosynthesis. This food can be used immediately, stored for later use, or used by other organisms. • Identify ways in which ecosystems have changed throughout geologic time in response to physical conditions, interactions among organisms, and the actions of humans. Describe how changes may be catastrophes such as volcanic eruptions or ice storms. • Recognize that biological evolution accounts for the diversity of species developed through gradual processes over many generations.		• Describe and explain the manufacturing systems of custom and mass production. • Explain and give examples of the impacts of interchangeable parts, components of mass-produced products, and the use of automation, e.g., robotics. • Describe a manufacturing organization, e.g., corporate structure, research and development, production, marketing, quality control, distribution. • Explain basic processes in manufacturing systems, e.g., cutting, shaping, assembling, joining, finishing, quality control, and safety. • Describe and explain parts of a structure, e.g., foundation, flooring, decking, wall, roofing systems. • Identify and describe three major types of bridges (e.g., arch, beam, and suspension) and their appropriate uses (e.g., site, span, resources, and load). • Explain how the forces of tension, compression, torsion, bending, and shear affect the performance of bridges. • Describe and explain the effects of loads and structural

Earth and Space Science	Life Science	Physical Sciences	Technology/Engineering
Grades 6-8			
			• Identify and compare examples of transportation systems and devices that operate on each of the following: land, air, water, and space. • Given a transportation problem, explain a possible solution using the universal systems model. • Identify and describe three subsystems of a transportation vehicle or device, i.e., structural, propulsion, guidance, suspension, control, and support. • Identify and explain lift, drag, friction, thrust, and gravity in a vehicle or device, e.g., cars, boats, airplanes, rockets. • Explain examples of adaptive or assistive devices, e.g., prosthetic devices, wheelchairs, eyeglasses, grab bars, hearing aids, lifts, braces. • Describe and explain adaptive and assistive bioengineered products, e.g., food, bio-fuels, irradiation, integrated pest management.

Appendix II: Core Learning Standards for a Two-Year Integrated Science Sequence for Grades 9 and 10

Earth and Space Science	Biology	Chemistry	Physics
• Explain how the transfer of energy through radiation, conduction, and convection contributes to global atmospheric processes, e.g., storms, winds. • Explain how the revolution of the earth and the inclination of the axis of the earth cause the earth's seasonal variations (equinoxes and solstices). • Explain the dynamics of oceanic currents, including upwelling, density and deep water currents, the local Labrador Current, and the Gulf Stream, and their relationship to global circulation within the marine environment and climate. • Describe how glaciers, gravity, wind, temperature changes, waves, and rivers cause weathering and erosion. Give examples of how the effects of these processes can be seen in our	• Describe the composition and functions of the four major categories of organic molecules (carbohydrates, lipids, proteins, and nucleic acids). • Relate cell parts/organelles to their functions. • Differentiate between prokaryotic cells and eukaryotic cells, in terms of their general structures and degrees of complexity. • Distinguish between plant and animal cells. • Explain the role of cell membranes as a highly selective barrier (diffusion, osmosis, and active transport). • Provide evidence that the organic compounds produced by plants are the primary source of energy and nutrients for most living things. • Explain the interrelated nature of photosynthesis and	• Identify and explain some of the physical properties that are used to classify matter, e.g., density, melting point, and boiling point. • Explain the difference between mixtures and pure substances. • Describe the four states of matter (solid, liquid, gas, plasma) in terms of energy, particle motion, and phase transitions. • Identify the major components of the nuclear atom (protons, neutrons, and electrons) and explain how they interact. • Compare nuclear fission and nuclear fusion and mass defect. • Explain the relationship of an element's position on the periodic table to its atomic number and mass. • Explain how atoms combine to form	• Explain the relationship between mass and inertia. • Interpret and apply Newton's first law of motion. • Interpret and apply Newton's second law of motion to show how an object's motion will change only when a net force is applied. • Understand conceptually Newton's law of universal gravitation. • Interpret and provide examples that illustrate the law of conservation of energy. • Relate thermal energy to molecular motion. • Differentiate between wave motion (simple harmonic nonlinear motion) and the motion of objects (nonharmonic). • Recognize the measurable properties of waves (e.g., velocity, frequency,

Earth and Space Science	Biology	Chemistry	Physics
local environment. • Explain how water flows into and through a watershed, e.g., aquifers, wells, porosity, permeability, water table, capillary water, runoff.	cellular respiration. • Describe and compare the processes of mitosis and meiosis, and their role in the cell cycle. • Describe the structure and function of DNA, and distinguish among replication, transcription, and translation.	compounds through both ionic and covalent bonding. • Balance chemical equations by applying the law of conservation of mass. • Describe the process by which solutes dissolve in solvents.	wavelength) and explain the relationships among them. • Distinguish between mechanical and electromagnetic waves.

Earth and Space Science	Biology	Chemistry	Physics
• Describe the rock cycle, and the processes that are responsible for the formation of igneous, sedimentary, and metamorphic rocks. Compare the physical properties of these rock types. • Describe the absolute and relative dating methods used to measure geologic time, e.g., index fossils, radioactive dating, law of superposition, and cross-cutting relationships. • Trace the development of a lithospheric plate from its growing margin at a divergent boundary (mid-ocean ridge) to its destructive margin at a convergent boundary (subduction zone). Explain the relationship between convection currents and the motion of the lithospheric plates. • Explain how the sun, earth, and solar system formed from a nebula of dust and	• Use a Punnett Square to determine the genotype and phenotype of monohybrid crosses. • Describe how the taxonomic system classifies living things into domains (eubacteria, archae-bacteria, and eukaryotes) and kingdoms (animals, plants, fungi, etc.). • Explain how biotic and abiotic factors cycle in an ecosystem (water, carbon, oxygen, and nitrogen). • Use a food web to identify and distinguish producers, consumers, and decomposers, and explain the transfer of energy through trophic levels.	• Identify and explain the factors that affect the rate of dissolving, i.e., temperature, concentration, and mixing. • Define Arrhenius' theory of acids and bases in terms of the presence of hydronium and hydroxide ions, and Bronsted's theory of acids and bases in terms of proton donor and acceptor, and relate their concentrations to the pH scale.	• Describe the electromagnetic spectrum in terms of wavelength and energy, and be able to identify specific regions such as visible light.

Earth and Space Science	Biology	Chemistry	Physics
gas in a spiral arm of the Milky Way Galaxy about 4.6 billion years ago.			

Appendix III: Additional Activities to Enhance the Learning Standards

In this appendix are additional activities to enhance the learning standards. Activities in regular type are Ideas for Developing Investigations and learning Experiences, those in italics are Suggested Extensions to learning in Technology/Engineering.

Earth and Space Science

Grades PreK-2

Standard #1

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

Standard #2

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

Standard #4

- Record the temperature outdoors in a sunny location and a shady location. Discuss the reason for the difference in temperature.
- Grade 2: Do as above on a sunny day and then repeat on a cloudy day at the same times and locations.

Standard #5

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

Grades 3-5

Standard #1

- Observe and describe the differences between quartz and mica.
- With a hand lens, examine a sample of coarse sand containing many kinds of grains. Also examine a collection of local rocks. Notice that rocks usually contain grains of many different minerals and that sand grains can be pure minerals, e.g., quartz, mica, etc.

- Show examples of items made from minerals, e.g., jewelry, aluminum foil, cans, glass bottles, etc.
- *Visit a glass factory, or an aluminum or tin production plant. (T/E 1.1, 1.2)*
- *Arrange a visit with experts who work with minerals, e.g., gemologist. (T/E 1.1, 1.2)*
- *Discuss how minerals are used in industry/technology, e.g., diamonds for drilling. (T/E 1.1)*

Standard #2
- Acquire a collection of minerals that includes (a) duplicates of the same mineral, somewhat different in appearance (size, shape, exact color) and (b) samples of minerals that look similar but are actually different. Sort as accurately as possible. Test all samples using three field tests: magnetism, streak, and hardness. Resort the minerals if this new information changes prior conclusions about samples being identical or not.
- Use a field guide to identify the minerals that you have described above. Compare your list of physical properties with those given in the guide.

Standard #3
- Approximate the role of heat in the formation of metamorphic rocks. Use dry cereal, marshmallows, and chocolate chips to represent three different minerals. Study and record the properties of each “mineral.” Combine and bake. Study properties of the “rocks” and new “minerals” formed by heat. Contrast to preexisting “minerals.”
- Approximate the role of pressure in the formation of metamorphic rocks. Snap wooden toothpicks in half, leaving them connected. Make similar piles of these “mineral grains” side by side on a tray. Place large books on top of one pile and press. Observe differences in the “rocks” brought about by pressure.
- Explain how the toothpick activity can also be used to represent the role of pressure in forming sedimentary rocks. Now the uncompacted toothpicks represent fresh grains of sediment.
- Illustrate the growth of crystals (important in forming both igneous and sedimentary rocks). Make concentrated solutions of various salts. Allow them to evaporate slowly and observe the formation of crystals. Commonly used salts include table salt (sodium chloride), alum, and Epsom salt.
- Visit a facility that utilizes rocks and minerals in construction materials. (T/E 1.1, 1.2)

Standard #4
- Engage in composting (worm farms).
- Construct a mini-landfill. Unearth and observe decomposition of buried waste, e.g., food, paper, plastic, metal. (T/E 2.1, 2.2, 2.3)

Standard #5
- Prepare different soil mixes using commercial potting soil, worm compost, and sand. Compare growth of plants in the different mixes.

- Fill clear jars half full with soil samples, then fill with water, shake, let settle, and observe the layers.

Standard #7
- Watch national/international weather broadcasts. Discuss the relationship between precipitation, temperature, and location on the globe.

Standard #8
- Create weather maps using basic symbols showing weather patterns, precipitation, etc. Students present their own weather report to the class.
- Grade 3: Watch local weather reports on television and in the newspaper.
- Grades 4-5: Attempt to forecast the weather for the next day and explain reasons for the forecast.

Standard #10
- Demonstrate in the classroom evaporation, condensation, and precipitation.
- Show on a diagram of the water cycle the effects of regional weather events such as heavy rainstorms, heavy winter snow totals, and droughts.
- Have students brainstorm and act out the water cycle. (See Incredible Journey/ Project WET in internet resource list.)
- Place white flowers (e.g., carnation, rose) in vase with food coloring added to the water. Observe change in flower color and relate to uptake of pollution by plants.
- Create a simple presentation showing the water cycle. (T/E 2.2)

Standard #12
- Visit local sites that show examples of the earth changing due to slow processes (e.g., schoolyard, coastline, erosion at Walden Pond) and rapid processes (e.g., localized erosion at Nauset Beach after a large storm). Document the changes using newspaper photographs.
- Visit local sites that show the effects of glacial advance or retreat on the landscape, e.g., drumlins, kettle ponds, etc.
- Observe the effect of winter weathering on roads.
- *Discuss the scales (e.g., the Richter Scale) used to measure earth events. (T/E 2.2)*
- *Compare a beaver dam with a manmade dam. What effects on the environment does each have? (T/E 2.4)*

Standard #14
- Create a model of the solar system and, using a flashlight, demonstrate the effects of the earth's rotation and revolution. (T/E 2.2, 2.3)

Standard #15
- Using a model (light source and sphere), demonstrate how the various phases of the moon are formed.

Grades 6-8

Standard #1

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

Standard #3

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

Standard #6

- Look at maps and photos to observe coastal changes.

Standard #7

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

Standard #8

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

Standard #9

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

Standard #10

- Model day and night using a dim bulb and a ball.

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

Life Science (Biology)

Grades PreK-2

Standard #1

- Using string, mark out a circle of about two meters in diameter in the schoolyard or a nearby park. Have students survey the biodiversity of the circle. Younger students can look for leaves of different shapes and older students can find out how many different types of plants and animals are found in the circle. Ask how the living things in the circle might be different in different seasons, then test predictions by going out to see.
- *Design and build several cardboard boxes, each of which has a small round opening at a different location on the box. Cover newly germinating seeds with the various boxes and observe how the stems grow toward the light that comes through the openings. (T/E 2.3)*
- *Build a terrarium containing plants and small animals, e.g., earthworms, other soil organisms, and insects. Discuss the needs of living things and let the students participate in maintenance of the terrarium. (T/E 1.1, 1.2, 1.3)*

Standard #2

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

Standard #3

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

Standard #6

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

Standard #7

- Discuss animals that hibernate. Some examples from Massachusetts are the garden snail, box turtle, chipmunk, woodchuck, black bear, and bat.
- In the fall, collect samples of the food items (seeds, nuts, grains) that a local chipmunk would store to eat while hibernating. Keep in a dry place over the winter. Notice that these

foods do not spoil. Notice that they cannot be found outdoors in the winter. Discuss the high nutritional value of these foods for animals.

- Discuss how animals' fur changes to prepare for winter and compare with what humans do to prepare for winter.
- Compare winter adaptations of wild mammals native to the area, e.g., squirrels, woodchucks, mice, raccoon, deer, bats, coyotes, etc.
- Discuss what happens to leaves that fall in the woods each year (decomposition).
- Explore objects and technologies used to make human life comfortable during the four seasons and bring examples or pictures of examples from home, e.g., air conditioner, fan, winter coat, wool hat. (T/E 1.1, 2.1)

Standard #8

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

Grades 3-5

Standard #2

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

Standard #3

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

Standard #5

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

Standard #6

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

Standard #7

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

Standard #9
- Use a sunflower or tulip and observe the ability of the flower to sense light intensity.
- Observe plants' responses to stresses in their environment, e.g., changes in salinity levels or flooding amounts in the salt marsh.

Standard #11
- Compare a coastal food chain to an inland food chain.

Grades 6-8
Standard #12
- Discuss reasons for the extinction of dinosaurs. Sudden change in climate? Drought? Catastrophic geological events?

Standard #13
- Look at the dispersal of pollen by bees and other insects to enable the reproduction and propagation of plants.
- Investigate the interactions of organisms in a local environment.
- In a wooded area, observe the ecosystem contained in the leaf litter and discuss how it sustains the larger ecosystem of the forest.

Standard #15
- Observe and document the effects of decay on materials (e.g., fruits) left to rot.
- Establish a compost bin. Analyze the decay of the contents and the gradual appearance of various organisms over time.
- Investigate wetland soil. Discuss how organic material is broken down more slowly in anaerobic conditions.

Standard #17
- Research natural and human-caused changes in some of the large-scale ecosystems (biomes) on earth.
- Use computer simulations to model the growth of plants on a plot of land or a sand dune or after a volcanic eruption.
- Review the data (on web sites) gathered by scientists who are conducting long-term ecological research. How are they monitoring sea level rises?
- Observe movement of barrier beaches seasonally. Compare jettied and non-jettied beaches.
- Investigate the effects of a tidal restriction on a salt marsh.
- Compare ecosystems with low and high biodiversity, e.g., salt marsh has low biodiversity, rainforest has high biodiversity. Discuss the timeframe that species have had to adapt, noting the impact of glaciation on ecosystems close to the poles.

Physical Sciences

Grades PreK-2

Standard #1

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

Standard #2

- Get three small transparent closed containers. In each put a different small solid object, e.g., marble, screw, eraser. Partly fill each of three more containers with a different liquid, e.g., water, oil, honey. Manipulate the closed containers. Note the property shared by all solids (they have definite shape) but not liquids.
- Observe water as it changes from a solid (ice) to a liquid (water).
- Using a piece of paper, design a container that can be filled with water. Explore how many times the container can be filled with water before it falls apart. Discuss why some designs may be more effective than others. (T/E 1.1, 1.2)

Standard #3

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

Standard #4

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

Standard #5

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

Grades 3-5

Standard #1

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

Standard #6

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

Standard #8

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

Standard #9

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

Standard #12

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

Grades 6-8

Standard #3

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

Standard #4

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

Appendix IV: Topical Outline of the Science and Technology/Engineering Curriculum Framework

Earth and Space Science

Broad Topic	Topics PreK-2	Topics Grades 3-5	Topics Grades 6-8	Topics Grades 9/10
Structure of the Earth System	Earth's Materials 2 Weather 1 Sun as a Source of Heat and Light 1	Rocks and their Properties 3 **Soil 2** Weather 4 Water Cycle 2	**Mapping the Earth 1** **Earth's Structure 1** Heat Transfer in the Earth System 2	Matter and Energy in the Earth System 12/14 Earth's Sources of Energy 0/6
Earth's History		Earth's History 1	Earth's History 3	Earth Processes and Cycles 9/22
Earth in the Solar System	Periodic Phenomena 1	The Earth in the Solar System 3	The Earth in the Solar System 5	The Origin and Evolution of the Universe 4/8
# of Learning Standards	**5**	**15**	**12**	**25 core/50 total**

Life Science

Broad Topic	Topics PreK-2	Topics Grades 3-5	Topics Grades 6-8	Topics Grades 9/10
The Characteristics of Organisms	Characteristics of Living Things 2	Characteristics of Plants and Animals 1	Classification of Organisms 1	
				Chemistry of Life 4/5
		Plant Structures and Functions 1	Structure and Functions of Cells 3	Structure and Functions of Cells 9/10
			Systems in Living Things 2	Human Anatomy and Physiology 0/2
Life Cycles and Heredity	Life Cycles 1	Life Cycles 2		
	Heredity 1	Heredity 1	Reproduction and Heredity 3	Genetics 6/9
			Evolution and Biodiversity 3	Evolution and Biodiversity 3/3
Organisms and Their Environment	Living Things and Their Environment 3	Adaptations of Living Things 5	Living Things and Their Environment 1	Ecology 2/5
		Energy and Living Things 1	Energy and Living Things 3	

			Changes in Ecosystems Over Time 2	
# of Learning Standards	**7**	**11**	**18**	**24 core/34 total**

Physical Sciences

	Broad Topic	Topics PreK-2	Topics Grades 3-5	Topics Grades 6-8	Topics Grades 9/10
CHEMISTRY	***Properties of Matter***	Observable Properties Of Objects 1	Properties of Objects and Materials 1	Properties of Matter 4	Properties of Matter 4/4
		States of Matter 1	States of Matter 2		
				Elements, Compounds and Mixtures 6	Atomic Structure 4/11 Periodicity 4/4 Chemical Bonding 4/7
CHEMISTRY	***Chemical Reactions***				Chemical Reactions and Stoichiometry 3/6 Gases and Kinetic Molecular Theory 2/6 Solutions 2/7 Acids and Bases 1/6 Equilibrium and Kinetics 1/5 Thermochemistry 0/4 Oxidation-Reduction and Electrochemistry 0/7

# of Chemistry standards		2	3	10	25 core/67 total
PHYSICS	*Motion and Forces*	Position and Motion of Objects 3		Motion of Objects 2	Motion and Forces 9/12
	Energy		Forms of Energy 2 Electrical Energy 3 Magnetic Energy 2 Sound Energy 1 Light Energy 1	Forms of Energy 1 Heat Energy 3	Conservation of Energy and Momentum 4/6 Heat and Heat Transfer 2/4 Waves 4/9 Electromagnetism 2/6 Electromagnetic Radiation 2/4
# of Physics standards		**3**	**9**	**6**	**23 core/41 total**
Total # Physical Science		**5**	**12**	**16**	**48 core/108 total**

Technology/Engineering

Broad Topic	Topics PreK-2	**Topics Grades 3-5**	**Topics Grades 6-8**	**Topics Grades 9/10**
Materials and Tools	**Materials and Tools 3**	Materials and Tools 3	Materials, Tools, and Machines 3	
The Engineering Design Process	Engineering Design 2	Engineering Design 4	Engineering Design 6	Engineering Design 5/5
			Communication	Communication

The Designed World			Technologies 4 Manufacturing Technologies 4 Construction Technologies 4 Transportation Technologies 4 Bioengineering Technologies 2	Technologies 3/5 Manufacturing Technologies 1/3 Construction Technologies 3/6 Energy and Power Technologies Fluid 2/6 Thermal 3/5 Electrical 4/6
# of Learning Standards	**5**	**7**	**27**	**21 core/36 total**

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

The following list of broad topics is suggested for science and technology/engineering teachers who, together with their colleagues in social studies, history, economics, and other areas of study, may want to help students better understand the historical and social dimensions of science and technology/engineering. Study of these topics helps underline the extent to which scientific debate and technological change play a vital role in our local, regional, national, and international communities. Interested teachers should ensure that these topics are taught at appropriate grade levels and linked to content learning standards.

I. The history of science

For this topic, students might study:

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

II. The nature of science

For this topic, students might study:

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

III. Benefits of science and technology/engineering

For this topic, students might study:

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

- Key discoveries and inventions and their beneficial uses, e.g., radium and the X-ray.

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

For this topic, students might study:

- How government, industry, and/or individuals may be responsible for negative effects (discuss examples here in Massachusetts, the United States, and abroad).
- Damage to the environment or ecosystems in this country and elsewhere, e.g., from pesticides, clearcutting, dumping of toxic wastes, overfishing, and industrial reliance on soft coal for energy.
- Some sources of damage or pollution, e.g., human ignorance, overuse or abuse of natural resources.
- Unanticipated ethical dilemmas, e.g., genetic cloning, contraceptives.

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

For this topic, students might study:

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

Appendix VI: Facilities, Safety Practices, and Legal Issues

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

Facilities and materials

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

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

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

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

There are many aspects to safe lab practices, including having appropriate protective equipment available, keeping the area clean and equipment in good working order, having appropriate disposal containers, providing sufficient accessible workspace, using proper storage and labeling, and having first-aid kits readily accessible. Proper use of and care for tools is a crucial part of learning science and technology/engineering, and teachers should be conscious that their own behavior and use of the equipment will be modeled by students. Particular precautions should be taken in the handling of any living or nonliving organisms brought into the classroom. Organisms should come only from a reputable supplier. Teachers should be aware of and strictly observe safety measures in labeling, storing, and disposing of chemicals used the laboratory. Many schools are making efforts to minimize or entirely eliminate the use of mercury in the laboratory. Some traditional uses for mercury, e.g., making thermometers, can be done as effectively with water or other substances. When mercury is needed, you may wish to place a very small layer of water on top of the exposed mercury to prevent the mercury from vaporizing. The water will evaporate and you will have to replenish it. In experiments calling for balloons, be aware that latex balloons are a choking hazard for young children and that students of any age may have allergic reactions to latex.

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

Eye protection

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

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

Legal issues

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

Dissection

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

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

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

	Strongly Agree	Agree	Cannot Judge	Disagree	Strongly Disagree
I Scientific and Technological Contents					
Reflect the learning standards in the Science and Technology/Engineering Curriculum Framework					
Are scientifically and technologically accurate					
II Features					
Provide descriptions of the achievements of historically important scientists and engineers					
Contain illustrations of contemporary children and adults that reflect the diversity of our society					
Include clear instructions on using tools, equipment, and materials, and on how to use them safely in learning activities					
Include a master source of materials and resources					
Provide student texts, booklets, or printed material and accompanying teacher manuals					
Provide coherent units that build conceptual understanding					
Provide for in-depth investigations of major scientific and technological concepts					
Incorporate applications of science and technology					
Highlight connections within science and technology and with mathematics and social sciences where relevant					
III Learning Activities					
Involve students in active learning and inquiry					
Clarify appropriate use of instructional technology such as calculators and computers					
Show how instructional technology can help students visualize complex concepts, analyze and refine information, and communicate solutions					
Provide multiple ways for students to explore					

	Strongly Agree	Agree	Cannot Judge	Disagree	Strongly Disagree
concepts and communicate ideas and solutions					
Are developmentally appropriate and provide for different abilities and learning paces					
Encourage discussion and reflection					
Draw on a variety of resources, e.g., trade manuals, measuring tools, other tools and machines, manipulatives, and the internet					
IV Teacher Support Materials					
Provide a clear conceptual framework for the concepts and skills taught					
Offer ideas for involving parents and community and keeping them informed about the programs					
Give suggestions for a variety of pedagogical strategies, such as open-ended questioning, direct instruction, practice, discussion, and cooperative learning					
Reference resource materials, such as appropriate videos, file clips, reference books, software, video laser disk, long-distance learning, CD-ROM, and electronic bulletin boards					
Suggest how to adapt materials for students with differing levels of achievement					
Suggest enrichment and skill reinforcement activities for extended learning					
Include suggestions for a variety of assessment approaches such as portfolios, journals, projects, and informal and formal tests					
V Student Assessment Materials					
Are free of inappropriate or derogatory material					
Occur throughout the unit, not just at the end					
Incorporate multiple forms of assessment, such as oral presentations, written reports, teacher observations, performance assessments, quizzes, and pre- and post-tests					
Focus on the acquisition of skills and concepts as well as on the learning process					
VI Program Development and Implementation					
Have field test data showing positive effects on student learning					
Are adaptable to local curriculum and/or school					
Offer training and long-term follow up for					

	Strongly Agree	Agree	Cannot Judge	Disagree	Strongly Disagree
teachers					

Glossary of Selected Terms

Adaptation modification of an organism or its parts that makes it more fit for existence under the conditions of its environment.
Atmosphere the gaseous envelope of a celestial body (as a planet).
Biotechnology Any technique that uses living organisms, or parts of organisms, to make or modify products, improve plants or animals, or to develop microorganisms for specific uses.
Climate the average course or condition of the weather at a place usually over a period of years as exhibited by temperature, wind velocity, and precipitation.
Communication The successful transmission of information through a common system of symbols, signs, behavior, speech, writing, or signals.
Conductor A material capable of transmitting another form of energy (as heat or sound).
Constraint A limit to the design process. Constraints may be such things as appearance, funding, space materials, and human capabilities.
Construction The systematic act or process of building, erecting, or constructing buildings, roads, or other structures.
Consumer An organism requiring complex organic compounds for food which it obtains by preying on other organisms or by eating particles of organic matter.
Decomposer Any of various organisms (as many bacteria and fungi) that return constituents of organic substances to ecological cycles by feeding on and breaking down dead protoplasm.
Design An iterative decision-making process that produces plans by which resources are converted into products or systems that meet human needs and wants or solve problems.
Design Brief A written plan that identifies a problem to be solved, its criteria, and its constraints. The design brief is used to encourage thinking of all aspects of a problem before attempting a solution.
Design Process A systematic problem solving strategy, with criteria and constraints, used to develop many possible solutions to solve a problem or satisfy human needs and wants and to narrow down the possible solutions to one final choice.
Ecosystem The complex of a community of organisms and its environment functioning as an ecological unit.
Electric circuit The complete path of an electric current including usually the source of electric energy.
Electric current A flow of electric charge.
Energy The capacity for doing work.
Engineer A person who is trained in and uses technological and scientific knowledge to solve practical problems.
Engineering The profession of or work performed by an engineer. Engineering involves the knowledge of mathematical and natural sciences (biological and physical) gained by study, experience, and practice, applied with judgement and creativity to develop ways to utilize the materials and forces of nature for the benefit of mankind.
Engineering Design The systematic and creative application of scientific and mathematical principles to practical ends such as the design, manufacture, and operation of efficient and economical structures, machines, processes, and systems.

Environment The complex of physical, chemical, and biotic factors (as climate, soil, and living things) that act upon an organism or an ecological community and ultimately determine its form and survival.
Erosion The gradual wearing away of rock or soil by physical breakdown, chemical solution, and transportation of material, as caused, for example, by water, wind, or ice.
Food chain An arrangement of the organisms of an ecological community according to the order of predation, in which each uses the next usually lower member as a food source.
Force An agency or influence that if applied to a free body results chiefly in an acceleration of the body and sometimes in elastic deformation and other effects.
Fossil A remnant, impression, or trace of an organism of past geologic ages that has been preserved in the earth's crust.
Gas/gas state Gas is a state of matter. Gas molecules do not hold together at all, so gas spreads out in all directions, including straight up. Gas changes both its shape and its volume very easily.
Habitat The place or environment where a plant or animal naturally or normally lives and grows.
Heat The energy associated with the random motions of the molecules, atoms, or smaller structural units of which matter is composed.
Igneous Formed by solidification of magma.
Inherited To receive from ancestors by genetic transmission.
Insulator A material that is a poor conductor (as of electricity or heat).
Life cycle The series of stages in form and functional activity through which an organism passes between successive recurrences of a specified primary stage.
Light An electromagnetic radiation in the wavelength range including infrared, visible, ultraviolet, and X rays and traveling in a vacuum with a speed of about 186,281 miles (300,000 kilometers) per second; *specifically* **:** the part of this range that is visible to the human eye.
Liquid/liquid state Liquid is a state of matter. Liquid molecules hold together weakly, so liquids flow. Liquids do not change their volumes significantly but do change their shapes easily.
Machine A device with fixed and moving parts that modifies mechanical energy in order to do work.
Magnetism A class of physical phenomena that include the attraction for iron observed in lodestone and a magnet, are inseparably associated with moving electricity, are exhibited by both magnets and electric currents, and are characterized by fields of force.
Manufacturing The process of making a raw material into a finished product; especially in large quantities.
Material The tangible substance (chemical, biological, or mixed) that goes into the makeup of a physical object. One of the basic resources used in a technological system.
Matter, states of Matter ordinarily exists in one of three physical states: solid, liquid, or gas. A given object's state depends on what the molecules are doing at the object's current temperature and pressure, i.e., are the molecules not holding together at all, holding together weakly, or holding together so tightly that they are locked into a stationary position. The transition between the states occurs at definite temperatures and pressures. A fourth state of matter, plasma (ionized gas in which the electrons are

separated from the nuclei), can exist at extremely high temperatures. Plasma is found on the sun and other stars.
Medium A substance regarded as the means of transmission of a force or effect.
Metamorphic rocks Are formed from preexisting rocks that are subject to very high pressure and temperature, which result in the structural and chemical transformation of the preexisting rocks.
Metamorphosis A marked and more or less abrupt developmental change in the form or structure of an animal (as a butterfly or a frog) occurring subsequent to birth or hatching.
Mineral A solid homogeneous crystalline chemical element or compound that results from the inorganic processes of nature.
Natural material Material found in nature, such as wood, stone, gases, and clay.
Orbit A path described by one body in its revolution about another (as by the earth about the sun or by an electron about an atomic nucleus).
Organism An individual self-sustaining unit of life or living material. Five forms of organisms are known: plants, animals, fungi, protists, and bacteria.
Pitch The property of a sound, and especially a musical tone, that is determined by the frequency of the waves producing it : highness or lowness of sound.
Plasma/plasma state Plasma is a state of matter, often called "the fourth state." The atoms in plasma move around in all directions at high speed. Plasmas are usually very hot and they glow. The sun, northern lights, lightning, and the glowing "gases" in neon sign tubes and fluorescent lamp tubes are examples of plasmas.
Precipitation A deposit on the earth of hail, mist, rain, sleet, or snow; *also* : the quantity of water deposited.
Process 1. Human activities used to create, invent, design, transform, produce, control, maintain, and use products or systems; 2. A systematic sequence of actions that combines resources to produce an output.
Producer Any of various organisms (as a green plant) which produce their own organic compounds from simple precursors (as carbon dioxide and inorganic nitrogen) and many of which are food sources for other organisms.
Prototype A full-scale working model used to test a design concept by making actual observations and necessary adjustments.
Reflection The return of light or sound waves from a surface.
Refraction Deflection from a straight path undergone by a light ray or energy wave in passing obliquely from one medium (as air) into another (as glass) in which its velocity is different.
Resource In a technological system, the basic technological resources are energy, capital, information, machines and tools, materials, people, and time.
Revolve To move in a curved path around a center or axis.
Rotate To turn about an axis or a center.
Sedimentary Rocks formed from material, including debris of organic origin, deposited as sediment by water, wind, or ice and then compressed and cemented together by pressure.
Simple machines The simple machines are the lever, pulley, and inclined plane, along with their most basic modifications, the wheel and axle, wedge, and screw. A complex machine is a machine made up of two or more simple machines.

Sketch A rough drawing that represents the main features of an object or scene and often made as a preliminary study.
Solar system The sun together with the group of celestial bodies that are held by its attraction and revolve around it.
Solid/solid state Solid is a state of matter. Solid molecules hold together very tightly and often line up in exact patterns, therefore, solids do not flow. Solids do not change their shapes or volumes.

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

Streak The color of the fine powder of a mineral obtained by scratching or rubbing against a hard white surface and constituting an important distinguishing characteristic. Note: the streak color may be completely different from the color observed at the surface of the mineral.
Synthetic Material Material that is not found in nature, such as glass, concrete, and plastics.
System A group of interacting, interrelated, or interdependent elements or parts that function together as a whole to accomplish a goal.
Technology 1. Human innovation in action that involves the generation of knowledge and processes to develop systems that solve problems and extend human capabilities; 2. The innovation, change, or modification of the natural environment to satisfy perceived human needs and wants.
Technology Education A study of technology, which provides an opportunity for students to learn about the processes and knowledge related to technology that are needed to solve problems and extend human capabilities.
Texture The nature of the surface of an object, especially as described by the sense of touch, but excluding temperature. Textures include rough, smooth, feathery, sharp, greasy, metallic, and silky.
Weather The state of the atmosphere with respect to heat or cold, wetness or dryness, calm or storm, clearness or cloudiness.
Weight The force with which a body is attracted toward the earth or a celestial body by gravitation and which is equal to the product of the mass and the local gravitational acceleration..

Selected Bibliography

American Association for the Advancement of Science, *Project 2061 - Technology: A Panel Report,* 1989.

American Association for the Advancement of Science, *Benchmarks for Science Literacy, Project 2061,* 1993.

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.

Blank, R. CCSSO and Pechman, E., *State Curriculum Frameworks in Mathematics and Science: How are They Changing Across the States?,* May 1995.

Boulanger, F.D., Instruction and science learning: A quantitative synthesis, *Journal of Research in Science Teaching,* 18: 311-327, 1981.

Bransford, J., Brown, A., and Cocking R., eds., *How People Learn: Brain, Mind, Experience, and School,* National Academy Press, Washington, DC, 1999.

Communities and Schools for Career Success (CS^2) and Corporation for Business, Work, and Learning, Task Force on Education Reform, *Integrating School-to-Work with Massachusetts Education Reform,* April 1997.

Duckworth, E., *The Having of Wonderful Ideas and Other Essays on Teaching and Learning,* New York: Teachers College Press, 1987.

International Society for Technology in Education, *National Educational Technology Standards for Students,* June 1998.

International Technology Education Association, *Standards for Technological Literacy: Content for the Study of Technology,* Reston, Virginia: International Technology Education Association, 2000.

International Technology Education Association and National Science Foundation, *Technology for All Americans Project, A Rationale and Structure for the Study of Technology*, 1996.

__________, *Standards for Technological Literacy: Content for the Study of Technology,* 2000.

Massachusetts Department of Education, *Massachusetts Science and Technology Curriculum Framework*, January 1996.

__________, *Guide to the Massachusetts Comprehensive Assessment System: Science and Technology*, January 1998.

__________, *Curriculum Frameworks Implementation Guide: Suggested Tools and Strategies, Draft*, July 1998.

__________, *PALMS Phase II Program Effectiveness Report 1998-1999, submitted to the National Science Foundation,* December 8, 1998.

__________, *PALMS Phase II May Report 1998-1999, submitted to the National Science Foundation,* May 15, 1999.

National Assessment Governing Board, U. S. Department of Education, *Science Performance Standards,* 1996.

__________, *What Do Students Know?*, 1996 NAEP Science Results for 4th, 8th and 12th Graders.

National Research Council, *National Science Education Standards.* Washington, DC: National Academy Press, 1996.

National Science Foundation, *Infusing Equity in Systemic Reform: An Implementation Scheme*, Washington, DC, January 1998.

National Science Foundation, *Statewide Systemic Initiatives 1998 Program Effectiveness Reviews Report,* January 1998.

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.

The Textbook League, *The Textbook Letter,* Sausalito, CA, www.textbookleague.org.

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

Wright, R. Thomas, *Technology Systems,* Tinley Park, Illinois: The Goodheart-Wilcox Company, Inc., 1996.

Selected Websites for Science and Technology/Engineering Education

Website	URL
General Science and Technology/Engineering Resources	
Center for Improved Engineering & Science Education	www.k12science.org/
Curriculum Library Alignment and Sharing Project (CLASP)	www.massnetworks.org/clasp/clasp.html
Eisenhower National Clearinghouse for Mathematics and Science Education	www.enc.org
Flinn Scientific	flinnsci.com
Laboratory Safety Institute	labsafety.org
Massachusetts Department of Education	www.doe.mass.edu
PALMS Initiative	www.doe.mass.edu/palms
Science and Technology/Engineering Curriculum Framework	www.doe.mass.edu/frameworks/current.html
Massachusetts Comprehensive Assessment System (MCAS)	www.doe.mass.edu/mcas/
Mathematics Curriculum Framework	www.doe.mass.edu/frameworks/current.html
NASA Classroom of the Future	www.cotf.edu/
NASAexplores (lessons and articles based on current research and developments)	nasaexplores.com/cgi-bin/index.pl
National Science and Technology Week	nsf.gov/od/lpa/nstw/start.htm
National Science Education Standards: An Overview	www.nap.edu/readingroom/books/nses/html/overview.html
National Science Foundation	www.nsf.gov
National Science Teachers Association's Scope, Sequence and Coordination Project	www.gsh.org/nsta_ssandc/
Public Broadcasting System's (PBS) TeacherSource database	pbs.org/teachersource/
Science & Safety: Making the Connection	sargentwelch.com/html/pdfs/ScienceandSafety.pdf
Science and technology news and discussion	www.bottomquark.com/
TERC (mathematics, science, and technology/engineering curriculum programs)	terc.edu
The Futures Channel	www.thefutureschannel.com/home.htm
The Jason Project	jasonproject.org

Third International Mathematics and Science Study (TIMSS)	www.ustimss.msu.edu
World Book online database	school.discovery.com/homeworkhelp/worldbook/atozscience/
Earth and Space Science	
Aeronautics and space resource for education	spacelink.nasa.gov/
Christa Corrigan McAuliffe Center for Education and Teaching Excellence	www.christa.org
Incredible Journey/Project WET	www.montana.edu/wwwwet/journey.html
Learning Adventures in Environmental Science	www1.umn.edu/bellmuse/mnideals/belllive.html
Science and Technology-Consortium for International Earth Science Information Network	www.ciesin.org/
Up-to-the-minute images and news flashes of NASA's planned mission to Mars	mars.jpl.nasa.gov/2001/
Life Science	
A guide to biology and chemistry educational resources on the web	biochemlinks.com/bclinks/bclinks.cfm

Website	URL
Food Science and Technology	foodscience.unsw.edu.au/
Resources for Food Science	members.tripod.com/~kburge/HomeEc/foodscience.html
U. S. Food and Drug Administration Center for Food Safety and Applied Nutrition	vm.cfsan.fda.gov/~dms/educate.html#educators
Physical Science	
Amusement park physics	www.learner.org/exhibits/parkphysics/
Technology/Engineering	
Design It! Engineering in After School Programs	www.edc.org/CSE/projects/destech.html
Discover Engineering	discoverengineering.org
Education Development Center, Inc. (science and technology/engineering projects)	edc.org
FIRST (For Inspiration and Recognition of Science & Technology) Robotics Competition	usfirst.org
FIRST Lego League (integrates robotics technology into the LEGO building system)	legomindstorms.com/first/
How Stuff Works	howstuffworks.com
International Technology Education Association	www.iteawww.org
Internet Science Technology Fair	istf.ucf.edu/
Journal of Technology Education	vega.lib.vt.edu/ejournals/JTE/jte.html
Junior Engineering Technical Society	www.jets.org
Massachusetts Institute of Technology's *Technology Review*	www.techreview.com
Massachusetts Pre-Engineering Program	masspepinc.org
National Engineers Week Future City Competition	futurecity.org
PBS's Building Big series	www.pbs.org/wgbh/buildingbig/
Preview of The New York State Department of Education's 8th Grade Technology Assessment	emsc.nysed.gov/ciai/mst/techedtest/online.html
Project Lead the Way	pltw.org
Tech Directions Online	www.techdirections.com
Technological Horizons in Education	www.techweb.com
Technological Literacy Assessment	sasked.gov.sk.ca/k/p_e/eval/tl_overview/
Technology Student Association	www.tsawww.org
TechWeb	www.techweb.com
Texas Elementary Technology	www.texastechnology.com

Education Lesson Plans	
The Great Technology Adventure: Technology Literacy for Elementary School Children	tsaweb.org/competition/adventure.htm#Introduction
United States Department of Transportation	education.dot.gov

XI
C.
NSF Proposal

K-6 Gets a Piece of the PIEE -

Partnerships Implementing Engineering Education

PROJECT SUMMARY

This project focuses on development of human resources related to grade K-6 Science, Math, Engineering and Technology education in an urban public school system, the Worcester (MA) Public Schools (WPS). The talent to be developed includes

- K-6 teachers, who must implement a new state-mandated Curriculum Framework for pre-engineering education;
- K-6 students (nearly half of whom are students of color, with minority numbers growing, whom we would like to encourage to consider technical careers); and
- graduate and undergraduate students at Worcester Polytechnic Institute (WPI) who are majoring in technical disciplines but who would like to gain experience in an educational setting and the sense of using their technical education in a helping role.

The total number of fellows per year are zero to five uP-Fellows and six to seven gP-Fellows, depending on the year of the project.

The goals of this project are:

1. To develop partnerships among graduate and undergraduate fellows, public school teachers and students, and WPI and WPI-affiliated faculty.

2. To implement the Massachusetts Science and Technology/Engineering Curriculum Framework (MSTECF) in the K-6 curriculum, by using the partnerships to develop specific teaching strategies. These strategies will use engineering design process and data collection analysis to teach math, science, writing and engineering.

3. To assess and disseminate:
   a. The outreach process we develop for recruiting fellows;
   b. Student learning outcomes of the K-6 engineering design curriculum;
   c. Teacher preparation that results from this project.

The 2001 Massachusetts Science and Technology/Engineering Curriculum Framework (MSTECF) can be found in the Supplementary Documents section of this proposal. Massachusetts is the first state to adopt a framework specifically including engineering/technology. It is planned that the Framework will enable teachers and administrators to strengthen curriculum and instruction from Prekindergarten (PreK) through grade 12. The program proposed here will provide the teachers in the WPS [and through documentation and dissemination, teachers throughout Massachusetts and beyond] hands-on and relevant examples and lesson plans to use to meet these Framework objectives for K-6, a set of grades presently not addressed as well as the middle and high school years.

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For font size and page formatting specifications, see GPG section II.C.

Appendix Items:

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

K-6 Gets a Piece of the PIEE - Partnerships Implementing Engineering Education

PROJECT DESCRIPTION

I. Goals and Objectives

This project focuses on development of human resources related to Kindergarten (K) through 6th grade Science, Math, Engineering and Technology (SMET) education in an urban public school system. The talent to be developed includes

- K-6 teachers, who must implement a new state-mandated Curriculum Framework for pre-engineering education;
- K-6 students (nearly half of whom are students of color, with minority numbers growing, whom we would like to encourage to consider technical careers); and
- graduate and undergraduate students at Worcester Polytechnic Institute (WPI) who are majoring in technical disciplines but who would like to gain experience in an educational setting and the sense of using their technical education in a helping role.

The elementary schools involved are middle schools in the Worcester Public Schools (WPS) system, "feeder" schools for a middle and high school in a quadrant already participating in an engineering pipeline project.

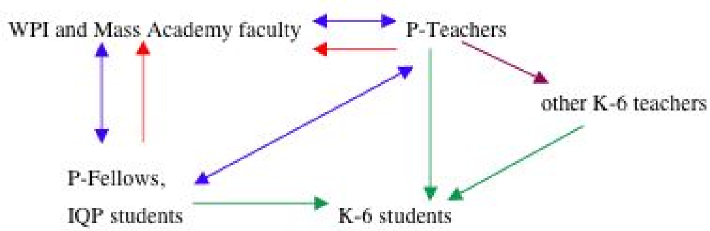

Figure 1: Partnerships described in this proposal.
Activity code: blue - curriculum development
red - reporting for project assessment purposes
green – instruction
purple - mentoring

The goals of this project are:

1. To develop partnerships among graduate and undergraduate P-Fellows*, P-Teachers, WPS K-6 students, and WPI and WPI-affiliated faculty. The relationships to be developed are shown in Figure 1, and are categorized as being part of curriculum

* P-Fellows stands for Partnership Fellows, the name given to the graduate and undergraduate fellowships described in this proposal. When a distinction is necessary, gP-Fellows and uP-Fellows are graduate and undergraduate Partnership Fellows, respectively. P-Teachers are the WPS teachers working on the teams, and are a subset of the general body of teachers in WPS.

development, reporting, instruction to K-6 pupils, and peer mentoring on the part of P-Teachers.

2. To implement the Massachusetts Science and Technology/Engineering Curriculum Framework (MSTECF) in the K-6 curriculum by using the partnerships described in Figure 1 to develop specific teaching strategies and curriculum. These strategies will use concepts from engineering design process, data collection, and analysis to teach math, science, writing and engineering.

3. To assess and disseminate:
    a. The curriculum developed and refined as part of this project;
    b. Student learning outcomes of the K-6 engineering design curriculum;
    c. P-Teacher preparation that results from this project.

The specific objectives are to produce the following:

1. A cadre of K-6 teachers proficient in science and engineering to support their colleagues in the Worcester Public Schools (WPS) on an ongoing basis once grant support ends. This structure will be designed to serve as a model for other school-college partnerships.

2. A set of lesson plans and lab activities, consistent with the MSTECF, for incorporating technology and engineering into the K-6 curriculum. These methods and materials will be transportable to other Massachusetts elementary schools, and should be adaptable to other states depending on their particular curriculum frameworks.

Specifically, we intend to develop a competitive program to select P-Fellows and to train them to mentor and support teacher teams. Each of the four WPS quadrants has an educational theme; the focus in the Doherty quadrant is science and engineering -- chosen in part to maximize the proximate relationship with neighboring WPI. The schools involved in this project will be from the ten elementary schools in the Doherty quadrant. This quadrant was chosen because we felt that it would have the highest potential for success (when compared to other quadrants in WPS) as the elementary teachers know that their students will be participating in programs related to engineering and technology in their subsequent education *and* there is currently no programming for these teachers to prepare them for teaching these topics. The P-Fellows will work with P-Teacher to assist them to design and implement activities in accord with the new Framework. The P-Teacher teams will be selected competitively so that, as part of their obligations, they will help disseminate their materials both within their school and then (after appropriate revisions) in other schools. The individuals from WPI and WPS together will plan the proposed activities collaboratively, i.e. based on each institution's experience with the other and their mutual self-interests.

II. Background

II.A. WPI

WPI (Worcester Polytechnic Institute), the third-oldest private university of engineering, science, management and the humanities in the United States, has been a pioneer in technological higher education since its founding in 1865. WPI was ranked among the top national universities in the 2000 edition of U.S. News and World Report's Best Colleges Guide and was ranked among the top national institutions in the magazine's Best College Values report. The current student body of over 3,700 men and women includes more than 1000 full- and part-time graduate students.

II.B The IQP Program

In 1970, WPI adopted a flexible and academically challenging program aimed at helping students learn *how to learn*. Known as "The WPI Plan", classroom experience is synthesized into projects that solve real-world problems. In addition to course requirements, students complete three projects. One is within the student's major, and is known as the Major Qualifying Project. A second is the Interactive Qualifying Project (IQP). This project is the equivalent of 9 credit hours and challenges students to investigate a topic examining how science or technology interacts with societal structures and values. The third graduation requirement is the Sufficiency, which is done on a theme within the Humanities and Arts.

The history and qualities of the IQP are important cornerstones of this project because one thematic focus for IQPs is "Education in a Technological Society." Students who choose this division frequently teach and/or develop curricula for grade levels from K through college. For example, a mathematics enrichment program was successfully designed and tested in a local middle school.[1] Another IQP developed a curriculum for the teaching of computer skills to children.[2] Other IQPs are already addressing the necessary development for the MSTECF challenge *for high school level work*, including new instructional hands-on projects on flight, robotics, and forces and motion.[3]

II.C Worcester Public School System (WPS)

The City of Worcester has a population of over 170,000 and is the second largest city in the state. It is diverse, with more than 46% of the WPS students being non-Caucasian. Section III.C describes how we intend to address the diverse population found in the WPS. The following is demographic information on WPS as recorded in 2000:

Enrollment by Grade:

PreK	K	1	2	3	4	5	6
835	2188	2313	2136	2159	2177	2083	2008

Enrollment by Race/Ethnicity (% of District):

Native American	0.5
African American	10.3
Asian	7.6
Hispanic	27.9
White	53.7

The WPS work with an inclusionary model. Students at the elementary level are heterogeneously grouped, not separated according to perceived ability. For example, students at Elm Park Community School include large numbers of at-risk students: students who are 2nd language learners, and underrepresented minorities, whose families are low-income and highly mobile.

II.D. K-6 Engineering Education in Massachusetts

Massachusetts is the first state to adopt an educational framework specifically including engineering/technology, and did so as part of the Massachusetts Education Reform Act of 1993. The 2001 Massachusetts Science and Technology/Engineering Curriculum Framework (MSTECF) can be found in the Supplementary Documents section of this proposal. This document describes the Massachusetts guidelines for learning, teaching, and assessment in science and technology/engineering. It is planned that the Framework will enable teachers and administrators to strengthen curriculum and instruction from Prekindergarten (PreK) through grade 12.

This proposal most directly addresses "Strand 4: Technology/Engineering." As examples: PreK-2 teachers need to treat topics such as "Identify tools and simple machines used for a specific purpose, e.g., ramp, wheel, pulley, lever." "Identify relevant design features (e.g., size, shape, weight) for building a prototype of a solution to a given problem" is a topic for Grades 3-5. By Grade 6, students should be able to "Identify and explain the components of a communication system, i.e., source, encoder, transmitter, receiver, decoder, storage, retrieval, and destination." The present challenge is that the teachers are in large part unprepared to teach these topics – even in the Doherty quadrant of WPS. The program proposed here will provide the teachers in the WPS [and through documentation and dissemination, teachers throughout Massachusetts and beyond] hands-on and relevant examples and lesson plans to use to meet these Framework objectives.

II.E. Massachusetts Academy of Mathematics and Science

In 1992 the Massachusetts Legislature, in cooperation with WPI founded the Massachusetts Academy of Mathematics and Science (Mass Academy). It is a fully accredited public high school for 11^{th} and 12^{th} grade students with an exceptional aptitude in mathematics and science. Since it is located at WPI, the students have access to extraordinary laboratory and research facilities. In addition, Mass Academy is committed to helping improve educational opportunities by helping to promote new teaching and learning methods through comprehensive professional development programs.

Pauline Lamarche, Principal of the Academy, has participated in every stage of developing this proposal, and will ensure that Mass Academy faculty, along with WPI faculty, implement the administration of the program effectively. She will draw upon ten years of Mass Academy experience in offering summer workshops to train public school teachers in new ways of teaching engineering. These workshops will be one of several models our collaborative will use to assure that the programs developed for the WPS P-Teachers fully meet their needs as well as those of their pupils.

II.F. Existing Partnerships

Unlike most technological universities, WPI has had a long and close relationship with the local public school system. This connection is unusual in that, like most technological universities, WPI does not have a department of education. However, WPI does have a small experimental teacher preparation program that was recently cited as one of the two best experimental models statewide.[4]

WPI's unique projects program has been the vehicle for WPI's collaboration with the public schools in Worcester. The single largest topical area of interest to students and faculty for IQPs (described in Section II.B) has been collaborations with public school teachers to improve the quality of pedagogy in mathematics and science. These projects have created a history of significant collaboration and personal connections between faculty and administrators at WPI and WPS.

As part of its mission, Mass Academy, upon request, delivers workshops and provides a range of professional development to the WPS.

Other recent initiatives between WPI and WPS include participation in a $250,000 planning grant and an $8 million full proposal (both funded) to the Carnegie Educational Foundation to replicate throughout Worcester small academies within larger schools, focusing on specific topics. WPI's contribution to this effort involves expanding our existing contributions to the Worcester Engineering Pipeline collaborative, working with nearby middle and high schools. Also, WPI is part of an NSF Teaching Enhancement program that is a collaboration between Tufts University, WPI, and the University of Massachusetts campuses at Lowell and Amherst. Tufts is the lead institution, and WPI will act as a local resource for teachers participating from our section of the state. This program is beginning in 2002-03 at the senior high level. Thus the present proposal, if funded, would be the first significant collaboration for engineering/technology curriculum development between the WPS K-6 levels and an institution of higher learning.

III. Project Plan

III.A. Overview:

In the short term, a considerable infusion of person power in the form of funded P-Fellows and IQP teams will be necessary to develop and pilot test the curriculum. The long-term steady state model will be one in which WPS teachers mentor each other, and IQP teams registered for academic credit provide ongoing support for curriculum updating and enhancement. To meet both the short- and long-term challenges, we have devised a scheme where a specific grade level is first addressed by P-Teachers with a relatively large support group. During the second year, the same grade level at a different school will use the teaching material and the support group will be smaller, aided by the documentation and experience gained by the previous year(s). The support group will be smaller still by the third implementation of the curriculum. By the completion of the funded project, this three-tier systematic structuring of support staff will be complete for the three grade levels used in the first year of the grant (grades 4, 5 and 6). Grades 2 and 3 will have had one year of intensive support and one year of reduced support, and grades K and 1 will have had one year of intensive support.

Year One:

We will begin by targeting contiguous grades (in the first year, grades 4, 5, and 6) in one school. We will assemble one team at each grade level, with a team consisting of 3 P-Teachers, 2 gP-Fellows from different disciplines, one IQP group (usually two to three students), and one WPI or Mass Academy faculty member. (We will henceforth refer to this team structure as the **Initiation Team**.)

The P-Teachers will meet with the PI and other senior personnel in the early summer of 2003 for planning sessions. The entire team (P-teachers, P-Fellows, IQP members and senior personnel) will participate in a week-long workshop later that summer. Both of these are described in Section III.B.1.

Once the school year starts, the gP-Fellows and an IQP group will assist the P-Teachers in the preparation, delivery, and assessment of the lessons. gP-Fellows will be expected to spend a total of about 20 hr/wk during the school year (36 weeks) in preparation, meeting, and contact time. IQP students will be expected to spend about 17 hr/wk for 21 weeks on similar types of activities. WPI faculty will be expected to devote a total of one month during the calendar year to the summer workshop and team activities. WPS P-Teachers will be expected to spend a total of about 120 hours, counting 35 hours of summer workshop time (which will include curriculum development) and two and one-half hours per week during the school year for team activities, such as meetings in excess of their usual class preparation duties. During the school year, P-Fellows and WPI faculty will serve as disciplinary content experts; IQP members will help prepare material; P-Teachers will deliver most classroom instruction and will serve as K-6 pedagogical experts.

Before the start of the next school year, there will continue to be (even after the grant expires) a summer workshop. After the first year, selected P-Teachers and P-Fellows who are experienced in the project will play an active role in delivering the next year's workshop.

Year Two:

In the second year of the project, there will be two types of teams.

The first type of team (henceforth referred to as the **Adaptation Team**) will be centered in grades 4, 5, and 6, but in a second school. This team will adopt and adapt the curriculum developed during the first year of the project, and so they will have just 1 gP-Fellow, 1 uP-Fellow (recruited from among those with IQP experience in the program in the previous year), and one-half month of WPI faculty time to support a team of three P-Teachers. In addition, this team will be mentored by experienced P-Teachers from the Year One Initiation Team and will participate in the summer workshops.

The second type of team in Year Two will be an Initiation Team (3 P-Teachers, 2 gP-Fellows, one IQP group, and one month of faculty time) that will now focus on grades 2 and 3 at the Year One school. Activities for this team will be similar to those described under Year One, but will develop curriculum appropriate to the different grade level.

Year Three:

In the third year of the project, there will be three types of teams.

One or more Initiation Teams will develop curriculum for the grades K and 1 in the Year One school.

One or more Adaptation Teams will transport the new Year Two curriculum (for grades 2 and 3) to additional schools.

One or more **Sustainability Teams** (consisting of 3 P-Teachers and one uP-Fellow or IQP group) will transport the Year One curriculum (for grades 4, 5, and 6) to additional schools.

After funding expires:

Sustainability Teams will continue to provide mentoring for expansion of the curriculum to additional schools and to new P-Teacher hires as needed. The vehicle will primarily be the week-long summer workshops. The P-Teachers and WPI students who run the workshops will be rewarded with academic credit from WPI (for students) and/or with modest funding from WPS. P-Teachers who serve as workshop facilitators or as trainees will continue to receive Professional Development Points (PDPs), applicable to required recertification. As they do now[3], IQP teams will continue to support efforts in the WPS, and Mass Academy can be an ongoing resource to teachers.

III.B. Training and Resources

III.B.1: Summer Workshops

First, a planning meeting for the P-Teachers, PI, and co-PIs will be held before the first summer workshop to better ensure that the workshop time will be used effectively and to determine any educational objectives that the P-Teachers have beyond those described in the curriculum frameworks.

We will then hold a weeklong summer workshop at WPI for the teams of P-Teachers and P-Fellows from the pilot schools. About half the workshop time will consist of formal sessions led by WPS personnel, Mass Academy experts, WPI personnel, and in years 2 and 3, selected P-teachers and P-Fellows already involved with the program. The goals will be to bring all team members to a common understanding of the MSTECF for that grade level, and to develop the students' (P-Fellows and IQP students) understanding of the basic elements of K-6 pedagogy. The WPS personnel to lead workshops will include Patrick DeSantis, K-8 Science Facilitator, who has years of experience working with classroom teachers and on teacher workshops on curriculum following the Curriculum Frameworks, lesson plans, and the Virtual Education Space (VES), described below. He is also a former WPS Teacher of the Year, and is recognized by nationally by BASF as an outstanding science teacher. Dr. Stephanie Blaisdell, WPI's Director of Diversity & Women's Programs and an expert on ensuring that topics related to engineering are presented in an attractive way to girls and students of color, will also participate.

The other half of the workshop time will be team time, devoted to preparation of specific lesson plans. This will include opportunities for the teams to review material that they can include in the coming school year, including but not limited to:

- the extensive number of IQP reports already completed on topics that bring science, mathematics and engineering into the classroom. Many of these reports address K-6, and all have components of testing the curriculum, assessing its value, and making recommendations for the future,
- inquiry-based workshops used in other WPI outreach programs, such as REACH[5] and programs administered through the Diversity and Women's Programs Office[6],
- related programs at WPI, such as the Teachers' Program of WPI's Center for Industrial Mathematics and Statistics – which brings eighty secondary teachers of mathematics to WPI for one week each summer. While at WPI, they will see how mathematics is used in industry, through lectures and, primarily, through participation in group projects focusing on real problems, and
- educational material developed during NSF-supported programs[7],

- existing material on the VES system.

VES is an electronic system that allows teachers and professional staff to access and input curricula and units to be shared by any and all WPS faculty and staff. Curriculum units and enhancement of the science, technology/engineering content in the elementary grades will be integrated into this system to be shared and accessed by all parties. VES has a searchable database of lesson plants, units and courses used successfully by teachers that align to the curriculum frameworks.[8] VES be reviewed so that the teachers are familiar with accessing it to download from and add to the body of information available to Massachusetts' teachers.

III.B.2: School-Year Activities

WPI will design its program to train our students with the help of the WPS, using existing close collaborative ties and a WPI for-credit course to prepare P-Fellows for mentoring responsibilities as well as possible eventual teaching careers. This course (entitled "Teaching Methods") deals with teaching methods for students intending to teach science or mathematics. Focus areas include curriculum planning, assessment, delivery of effective instruction, classroom management, equity, and professional responsibility.

As described in Section II.F, WPI has a small but effective teacher preparation program. We have ten juniors in the program in 2001-2002, and students from this program could also participate in the mentoring activities we are designing for the WPS classrooms. Although the students in the teacher preparation program are preparing for licensure in Grades 7-12, which involves a different set of credentialing than K-6 licensure, the infrastructure that is in place to support these students (such as the IQP; WPI and Massachusetts Academy faculty with close ties to the WPS and knowledge of and interest in pre-college education; and regular academic courses in cognitive psychology, cultural differences, and languages) will also support our g and uP-Fellows. Additional academic courses applicable to K-6 licensure are available on a cross-registration basis at nearby Colleges of Worcester Consortium institutions such as Worcester State College and Assumption College.

In addition to the summer activities, professional development of the P-Teachers will be accomplished through

- working with "Project Lead the Way" and the UMass/Raytheon Engineering Pipeline Collaborative (EPiC) to adapt and refine specific "engineering applications" for the elementary level,
- sessions facilitated by WPS Curriculum Liaisons on integration of Massachusetts Curriculum Frameworks in Science, Mathematics and English/Language Arts to build student capacity for the Engineering Pipeline in the WPS Doherty Quadrant, and
- 2.5 hrs. weekly meetings (total) with P-Fellows to develop appropriate strategies for teaching engineering.

III.B.3. Description of Curriculum Development

Through the activities described in this proposal and shown graphically in Figure 1, new curriculum will be developed and assessed for grades K-6. This curriculum will meet its challenges in the following ways:

- *Following the Curriculum Framework*: which will be reviewed by the summer workshop leaders and returned to during the school year. With the support of WPS curriculum specialists familiar with the MSTECF, WPI and WPS faculty will structure a curriculum strongly emphasizing the concept and practice of engineering as designing products and processes to help people.

- *Age appropriateness:* using the expertise of the P-Teachers. This will mean that the material should be hands-on and exploratory in nature. It is the translation of engineering and technology topics (traditionally taught to upper-level students) to K-6 students that will be the most exciting and rewarding part of this program, and the part that will use the partnerships between WPI/MassAcademy and WPS to its fullest extent.
- *Learning style appropriateness:* The Academic Resource Center at WPI has the facilities and experience to perform a range of learning style assessments.[9] The other side of learning styles, the development of appropriate teaching material, has been addressed by the WPI Center for Educational Development, Technology, and Assessment (CEDTA) through workshops [10]. These resources will be drawn upon during the summer workshops
- *Attractiveness to a diverse student body*: which will be reviewed in the summer workshops and returned to during the school year, particularly through the assessment process. For all students, this challenge will be partially met by providing as many different kinds of role models as possible, through the students and staff involved and the opportunity for 'guest lectures' in classrooms by WPI students (the selection of whom could be targeted for gender and racial balance). For girls in particular, this challenge will be met by showing ways that engineering can be used to help society, so important to girls when making plans for the future. [11] We will stress engineering as a "helping profession" because of our experience with using this theme to involve young people, especially women and minorities who have not traditionally viewed engineering as a profession that solves social problems.

One example of how this will be achieved is to develop material by drawing upon a workshop currently part of the WPI Camp REACH program[12]. For the past five years, we have conducted a disability awareness/rehabilitation engineering program for middle school girls. Activities focus on the problems faced by the disabled and to show how universal design benefit all persons. Currently, the specific activities include universal design (e.g., elevator controls) versus accommodation (e.g., restroom grab bars). Participants make measurements of the ADA compliance of buildings using the appropriate tools (tape measures, protractors, calipers, spring scales, inclinometers, and stopwatches) applied to hallways, stairs, and ramps. A variety of disabilities are simulated to show that some tools are difficult to use if one has limited dexterity or low vision. Writing exercises have been used, along with small group discussions and meetings with visitors who are physically-challenged.

This kind of unit meets the challenges described above because it would help PreK-2 teachers to encourage their students to "Identify tools and simple machines used for a specific purpose, e.g., ramp, wheel, pulley, lever." (part of the curriculum frameworks). While it is currently designed for 6th graders, it could be accommodated for younger children by the P-Teachers and P-Fellows (for example, by changing the amount of time spent on different activities and the expectations for self-discovery). It is learning-style appropriate because it has elements for Visual, Aural, Read/write, and Kinesthic learners. It is also a clear reminder of how engineers help people, which has already proven to be effective for the girls at Camp REACH.

III.C Outreach to Diverse Community

Because students of color make up nearly 47% of the WPS population and 28% are Latino, and because WPS students speak 84 languages and dialects and 25% do not speak English at home, our program design will focus on developing mentoring skills necessary for this audience. For such expertise we will rely heavily on the WPS personnel, who are already skilled at dealing with this student population. We also plan to heavily recruit participation of female and minority undergraduate and graduate students (see Section IV).

Both women and minorities are currently underrepresented in the engineering profession. For example, only 7.3% of practicing engineers are women. Full participation of women and minorities in engineering is needed, not only for reasons of equity, but for economic security. Studies indicate that a critical time in the "pipeline" of women into technological careers is the middle school years, when it is common for girls to lose interest in math and science.[13,14] For these reasons, the summer workshops will include training on presenting engineering in a positive way to girls and students of color. Since elementary school teachers are predominantly female, their excitement about the introduction of engineering and technology based units will provide wonderful role models to their female students.

III.D. Benefits to P-Teachers, P-Fellows, and Schools

The benefits to the P-Teachers will be current engineering and science knowledge, important especially for teachers struggling with new curriculum expectations. In addition, there will be strategies to implement the design as well as the data collection and analysis parts of the engineering Frameworks. We believe the P-Fellows will be effective in providing this support.

For the gP-Fellows, in addition to their stipends supporting their aspirations for graduate study, the program will help develop their potential as teachers at any level, K-graduate school. We do not intend to ask them to make any commitments to become public school teachers (but we would be delighted if some do so). The training programs for the P-Fellows will recognize their desire to "pay back to the community" through their teaching role. And the P-Fellows will also be committing to a program and a selection process to assure a high possibility that the P-Fellows will become involved in improving engineering education throughout their careers, after achieving their degrees at WPI.

The targeted schools and their pupils will benefit from the new curriculum. These students will be better prepared for their later years in the same science and engineering quadrant. Other schools, teachers and pupils will benefit from the dissemination, which will be aided electronically through the use of VES (described in Section III.B.1).

IV. Recruitment and Selection

IV.A. P-Teachers

Selection of WPS P-Teachers will be handled at the individual school level by the school's principal. This selection may not be competitive for a given school as there will be a limited number of candidates (for example, a limited number of teachers at a given grade level) possible for the positions. The P-Teachers will be expected to commit to the full program, both the summer workshop and the following school year. Preference will be given to teachers interested in becoming a resource and trainer for the program. Therefore, the real selection process will be to carefully chose elementary schools from the Doherty quadrant, using identified leaders in the first year a grade is addressed, and then expanding to include the other schools as the curriculum matures. There is administrative support within this quadrant because of the desire to create a seamless pipeline for the existing engineering and technology coursework in middle and high schools.

IV.B. Graduate Fellows (gP-Fellows)

Recruitment for gP-Fellows will take place within and outside of WPI. As described in Section II.B, many WPI undergraduates choose the IQP project topic area "Education in a Technological Society", and historically the most popular of these projects involve developing and teaching SMET curricula in the WPS. Such IQPs are a natural training ground for P-Fellows. In recruiting our gP-Fellows, we intend to target BS/MS students, who by definition have already obtained WPI undergraduate degrees. Our recruiting program will identify those BS/MS students who have completed educational IQPs, and will aim to establish a pipeline (but not the only route) from the IQP to a gP-Fellowship.

Year One (for students within and outside of WPI): Since there are activities planned from the spring of 2003, the gP-Fellows must be selected by June, 2003. In December of each year, the WPI Graduate Admissions Office begins processes to recruit for existing WPI fellowships. Applicants are asked to complete their admission application by February 1, and the fellowship application by February 15. We plan to modify the application form to include information necessary for selection to this program. At that time, with the recruitment funds available, the Graduate Admissions Office will send a mailing to all US applicants and prospective applicants. In addition, we will add it to the Graduate Admissions website, under Fellowships. We can send notifications to gP-Fellows out as early as March 1 and ask award winners to respond by the April 15 (the national reply date for graduate support) as they normally would.

To try to enhance the mentoring aspects of the P-Fellows and IQP students working in the classroom, we will make special efforts to advertise the P-Fellowships and IQP opportunities to women and students of color through WPI's Office of Diversity and Women's Programs, professional organizations [such as the National Society of Black Engineers[15] (NSBE), Society of Hispanic Professional Engineers[16] (SHPE), and Society of Women Engineers[17] (SWE)], and advocacy organizations (such as Women in Engineering Program Advocacy Network[18], National Consortium for Graduate Degrees for Minorities in Engineering and Science [19] , and Women in Technology International[20]). Seeing young women who are putting effort into giving back to their community should prove to be inspiring to the girls in the classroom.

Selection will be based on the applicant's previous experience and interest in teaching (including peer tutoring, etc.), and recommendations. It is not anticipated that academic records in the applicant's discipline will be pertinent (because they would also need to be separately admitted to WPI's graduate program) unless they include courses related to pedagogy. It will also be important to provide diversity in terms of the P-Fellows' disciplines. Given the range of material in the Curriculum Framework, we are targeting the Mechanical Engineering, Electrical and Computer Engineering, and Mathematical Sciences Departments. Letters from the pertinent people in these departments are included in the Supplementary Documents section of this proposal.

Currently, WPI has following kinds of graduate fellowships available: five Goddard, six endowed fellowships, three to six corporate, and six institute. The only one for which we require an application is the Goddard, for which we received 42 applications for the five awards. This shows that there is currently more interest in graduate fellowships at WPI than we have to offer.

Year Two: The number of gP-Fellows increases from six to seven in the second year of the program. It is anticipated that all of the gP-Fellows from Year One will continue in Year Two, so one (or more, if a gP-Fellow does not return) additional gP-Fellow will be recruited.

Year Three: In all likelihood there will be five new gP-Fellows this year, and one returning from the previous year. These P-Fellows will be recruited as described above. In addition, uP-Fellows involved with the program in Year Two would be good candidates for gP-Fellowships if they are admitted to the graduate program.

IV.C. Undergraduate Fellows (uP-Fellows)

uP-Fellows are part of the support mechanism in Years Two and Three. We will recruit for this position through the standard on campus mechanisms as well as to groups supporting women and students of color on campus (including the WPI chapters of NSBE, SHPE and SWE) and through the WPI Office of Minority Affairs. The students involved with the IQP groups from the previous year(s) would be ideal candidates as they would already be well-versed in the curriculum, project goals, etc. We will use previous teaching experience and interest, academic records and recommendations as parts of the selection process.

IV.D. IQP teams

IQP topics are advertised through an extensive website. [21] In addition, we can highlight this special opportunity for students through publications such as the student newspaper. IQP groups are usually formed three to six months before the start of the project, and we will use previous teaching experience and interest, academic records and recommendations as parts of the selection process.

V. Organization and Management

During all three years of this program, the PI will have overall responsibility for the administration of the award, the management of the project, and interactions with the NSF. She and the coPIs will divide the responsibility for various roles, including recruitment (described above), assignments to the different teams, working with the assessment consultant, and meeting with the P-Fellows and IQP students on regular bases.

A letter describing the school district participation is provided in the Supplementary Documents section of this proposal. Other aspects of Organization and Management are described in other sections of this proposal.

VI. Evaluation

Our evaluation plan will incorporate assessment of the following:

1. The outreach process we develop for recruiting gP- and uP-Fellows for K-6 education;
2. Student learning outcomes of the K-6 engineering design curriculum;
3. P-Teacher preparation that results from this project.

The outreach process we develop for recruiting P-Fellows will be evaluated using the following measures. Time points at which measurements will be taken are included in parentheses after each measure. Project year runs from June 1 - May 31; Year 0 refers to pre-project year.

- Success in filling the number of slots we have available with qualified P-Fellows, as measured by:
  - the number of complete teams compared with the planned number; (January of Years 1, 2. 3)
  - the ratio of the number of qualified applicants for student fellowships to the number of slots available; (September of Years 1, 2, 3)
- The extent to which the K-6 engineering curriculum becomes part of the ongoing IQP culture, as measured by the number of K-6 engineering IQPs completed each year; (May, Years 1, 2 3 Year 1 measurement will include comparison with two pre-project years)
- The satisfaction of the P-Teachers with their P-Fellows, as indicated by an objective questionnaire and narrative evaluation in the middle and end of the year of team activity. (January and May of Years 1, 2, 3)

Student learning outcomes of the K-6 engineering design curriculum will be measured in the following ways:

- Student success on the pertinent sections of the standardized statewide grade 4 Massachusetts Comprehensive Assessment System (MCAS) examinations, as compared between schools and classes with and without the GK-6 program, and within the same school before and after participation in the GK-6 program. We anticipate that scores within a given school will continue to rise for several years as successive generations of students participate in a curriculum that starts first in grade 4, then in grade 2, and then in K. (December of Years 1, 2, 3 including data from two pre-project years)
- Survey measures of student interest in SMET, analyzed in terms of underrepresented groups. (May of Years 0, 1, 2, 3)

P-Teacher preparation that results from this project will be measured by:

- Teacher participation over time. We expect teachers to "vote with their feet" for either a successful or an unsuccessful project; (December of Years 1, 2 3)
- A survey of the kind and amount of continuing education credit received by P-Teachers (December of Years 1, 2 3)
- A survey of how many P-Teachers are continuing to use the curriculum they developed at the end of the project; (April of Year 3)
- A tally of the extent of dissemination of the new curriculum through the schools of the Doherty quadrant; (April of Year 3)
- A survey and focus group of participating P-Teachers a year after their paid project participation, probing the extent to which they found the project useful in professional development, and the extent to which they have mentored other P-Teachers. (December of Years 1, 2 3)

The number of P-Fellows and P-Teachers anticipated to be involved in each of the years of the project is as follows:

Year 1: six gP-Fellows, nine P-Teachers

Year 2: three uP-Fellows, seven gP-Fellows, fifteen P-Teachers

Year 3: five uP-Fellows, six gP-Fellows, nine P-Teachers

The totals are five uP-Fellows, twelve distinct gP-Fellows, and forty-five P-Teachers, assuming that when possible, the P-Fellows are supported for two consecutive years.

An external assessment consultant will be hired part-time for each of the project to develop and administer the instrument and analyze the results of the assessment. Miller will oversee the work of the assessment consultant.

The participants (PIs, co-PIs, P-Fellows, P-Teachers, and IQP students) are prepared to cooperate in an overall program evaluation to be conducted by the NSF.

VII. Results from Prior Support

Nicoletti: received an NSF grant for the development of the REACH program in 1996. Camp REACH, now in its sixth year, is a two-week residential program at WPI. It brings thirty middle school girls from across Massachusetts to Worcester to generate interest and excitement about engineering and technology and the ways they can be used to help individuals, organizations, and society. The major innovation was that the girls learned what engineering is as a career by working as an engineer on a real, community service project. Discovery workshops were also developed to expose girls to a broad range of engineering and science topics through engaging, hands-on activities. Both a pre-camp orientation and a workshop on the last day of camp were held specifically for parents. We presented results at an NSF meeting, the 1997 Frontiers in Education Conference in an article entitled "REACH: An Engineering Summer Camp for Middle School Girls," and in an American Society for Engineering Education Conference presentation (June 2000) entitled "Lessons Learned While Inspiring Young Girls to Pursue Engineering." A website was developed: http://www.wpi.edu/~reach.

Miller: has had recent support from NSF and the Davis Educational Foundation, in both cases as PI. All projects concern improvement in higher education, but the pedagogical principles are largely transferable to pre-college education. An NSF IWR grant focused on developing curricular and conceptual "bridges" between pairs of introductory SMET courses, as a way of helping students see the relevance of introductory courses to their majors. Supported by a Davis Educational Foundation grant from 1992-1997, Miller and her colleagues developed and pilot tested a Peer-Assisted Cooperative Learning model that utilized undergraduate Peer Learning Assistants (PLAs) to facilitate cooperative learning groups in large introductory courses. Long-term assessment of outcomes showed that students who took PLA-assisted courses in their freshman or sophomore year achieved a small but statistically significant increased number of A and B grades in their junior and senior years, and that the effect was linear with the number of PLA-assisted courses taken. The same students experienced a 20% increase (from about 65% to 85%) increase in their freshman to junior retention rate, and a similar increase in their 4-year graduation rate, as a result of taking just one PLA-assisted course. These learning gains were achieved with a net savings in faculty time input, and a modest increase in course cost due to PLA wages.

A current project, also funded by the Davis Educational Foundation, aims to improve the first year experience through three interventions. *Insight* is a residentially based personal and academic development program in which students reside with their orientation groups, receive regular visits from faculty consultants/academic advisors in their residences, and get residence-based tutoring and personal development programming. *Course bridging* is based on the successful IWR project described above, and targets the introductory calculus course that is a major academic hurdle for incoming WPI freshmen. The *Tutorial* is modeled after the Oxford-Cambridge tutorial model, in which a small group of faculty and 25 freshmen spend all of their academic time together for the students' first semester at WPI. All three interventions aim to increase student connections with faculty and other students, and to improve freshman-sophomore retention (already quite high at 91%).

Mass Academy: received funding from the Massachusetts Department of Education (NSF PALMS) each of the last four years to conduct a week-long immersion workshop for teachers. The focus of each of the Summer Content Institutes was Engineering Problem Solving. Teachers from Massachusetts received food, lodging, and PDPs including optional graduate credits.

VIII. Faculty participants

PI: Dr. Denise Nicoletti, WPI Associate Professor of Electrical and Computer Engineering, will be PI. A tenured member of the ECE faculty, Prof. Nicoletti co-designed and developed Camp REACH, a 2-week summer residential program to introduce middle-school girls to engineering (initially funded by NSF and last offered July 22-August 3, 2001 for the fifth consecutive year). Prof. Nicoletti's professional experience through Camp REACH in training middle school teachers and WPI students about the engineering design cycle will be invaluable in structuring the P-Fellows and P-Teachers mentoring program. She is also experienced in managing, fund-raising, assessing and disseminating programs similar to this partnership program, as well as presenting oral and written scholarly presentations on such topics.

CoPI: Dr. Judith Miller, WPI Professor of Biology and Biotechnology and Director, Center for Educational Development, Technology and Assessment. Prof. Miller offers a graduate Seminar and Practicum in College Teaching and has extensive publications in pedagogical innovation and experience with mentoring future and new faculty. She will also direct program assessment.

Senior Personnel: Dr. John Goulet, Mathematical Sciences, Director of the WPI Masters of Mathematics for Educators (MME) program and Director of WPI Teacher Preparation programs. The MME program results in qualifications for Massachusetts Licensing in Secondary Education.

Senior Personnel: Dr. Lance Schachterle, Humanities, Assistant Provost, and Director of the Worcester Community Project Center. He is involved in engineering pipeline efforts in Worcester (the UMass/Raytheon Engineering Pipeline Collaborative, EPiC) as well as statewide (Engineering in Mass Collaborative) and co-directs the Worcester Community Project Center, which will supply undergraduate student teams to facilitate and help assess this proposed activity.

Senior Personnel: Pauline Lamarche, Principal, Massachusetts Academy of Mathematics and Science at Worcester; primary developer of Mass Academy teacher in-service programs.

The coPI for the WPS subcontract is Gale Hilary Nigrosh, Ph.D., Development Specialist For Higher Education & Business Partnerships of the Worcester Public Schools. She is charged with developing collaboratives between colleges, universities, businesses, and schools for research, staff development, and curriculum innovation, and with seeking appropriate financial support to sustain projects. With partner institutions, involved in the design, implementation and monitoring of a broad range of academic programs with particular focus on emerging biotechnology and health/science fields, pre-engineering, pre-service teacher training, math/science opportunities for women and minority students, programs in arts and humanities, and preparation for postsecondary education.

REFERENCED CITED

[1] Nicholas G. Gallagher, James A. Valis, "Tahanto Middle School Mathematics Enrichment Program (#99D235I)", WPI IQP advised by Denise Nicoletti, 1999.

[2] Scott Peter Desy, Seth Michael Dziengeleski, Lucas Given McCauslin, "Computers in Elementary Education (98D061I)," WPI IQP advised by J. F. Zeugner, 1998.

[3] Nicholas J. Cannata, Adam Robert Contardo, Surachate Kalasin, Patrick Thomas Shaver, "Design of Modules for Pre-Engineering Education (00B035I)," WPI IQP advised by J. S. Demetry.

[4] Massachusetts Acting Governor Jane Swift Governor's speech on the state of Massachusetts's education, Quincy, MA, August 30, 2001.

[5] http://www.wpi.edu/~+reach, accessed 5/21/02.

[6] http://www.wpi.edu/Admin/Diversity/, accessed 5/21/02.

[7] http://www.ehr.nsf.gov/esie/resources/, accessed 5/21/02.

[8] "NASBE Showcases Virtual education Space as an Exemplary Online Program," http://ves.mass.edu/newsandevents3.html, accessed 5/21/02.

[9] http://www.wpi.edu/Admin/ARC/schedule.html

[10] http://www.WPI.EDU/Academics/CEDTA/Reports/2001annualreport.html

[11] Stephanie Blaisdell, Factors in the Underrepresentation of Women in Science and Engineering, 1995.

[12] A. Hoffman, H. Ault, C. Demetry, D. Nicoletti, "Teaching Disability Awareness and Universal Design to Middle School Students," Designing for the 21st Century, 2000 Conference Proceedings, http://www.adaptiveenvironments.org/21century/proceedings5.php#pteaching.

[13] P. Orenstein, School Girls, Young Women, Self-Esteem and the Confidence Gap (New York: Doubleday, 1994), p. 23.

[14] S. Brush, "Women in Science and Engineering," American Scientist 79, 404-419 (1991).

[15] http://nsbe.org/, accessed 5/21/02.

[16] http://shpe.org/, accessed 5/21/02.

[17] http://www.swe.org/, accessed 5/21/02.

[18] http://wepan.org/, accessed 5/21/02.

[19] http://www.nd.edu/~gem/, accessed 5/21/02.

[20] http://www.witi.com/index-c.shtml, accessed 5/21/02.

[21] http://www.wpi.edu/Academics/Projects/, accessed 5/21/02.

FACILITIES, EQUIPMENT & OTHER RESOURCES

FACILITIES: Identify the facilities to be used at each performance site listed and, as appropriate, indicate their capacities, pertinent capabilities, relative proximity, and extent of availability to the project. Use "Other" to describe the facilities at any other performance sites listed and at sites for field studies. USE additional pages as necessary.

Laboratory:

Clinical:

Animal:

Computer: **Standard computer facilities available for word processing, webpage development, etc. including color scanners, printers and image manipulations software.**

Office:

Other: ____________________

MAJOR EQUIPMENT: List the most important items available for this project and, as appropriate identifying the location and pertinent capabilities of each.

OTHER RESOURCES: Provide any information describing the other resources available for the project. Identify support services such as consultant, secretarial, machine shop, and electronics shop, and the extent to which they will be available for the project. Include an explanation of any consortium/contractual arrangements with other organizations.

EXCERPTS FROM
Science and Technology/Engineering Curriculum Framework

May 2001

Massachusetts Department of Education
Address 350 Main Street, Malden, MA 02148
Telephone 781-338-3000 **Internet** www.doe.mass.edu

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May 2001

Dear Colleagues,

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

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

- Standards are more specific, to enable teachers to design instruction and assessment more effectively. Grade spans have narrowed from Prek-4, 5-8, 9-10 to Prek-2, 3-5, 6-8, 9-10.
- The four strands in the 1995 document (Inquiry, Domains of Science, Technology and Science, and Technology and Human Affairs) are now four content strands (Earth and Space Science, Life Science, Physical Sciences, and Technology/Engineering). "Inquiry" is now to be taught with the content of each domain of science.
- High school standards: The 2001 framework has a set of standards for comprehensive, full year courses in each of the four science domains, and in Technology/Engineering. In each domain, a subset of these standards has been identified as core. Only core standards will be assessed by MCAS. In addition, a set of core standards has been identified for a two-year, grade 9 and 10 integrated science program. These standards are a subset of the core standards from each of the four science domains.
- Format: The revised document has a three-column grid for grades Prek-5 that shows the topic and the Learning Standards, Ideas for Developing Investigations and Learning Experiences, and Suggested Extensions to Learning in Technology/Engineering.
- A glossary was added for selected Prek-8 terms and a topical outline was included.

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

- For grades Prek-K, students' sense of geologic time is strengthened in the earth science strand with the standard "Recognize that fossils provide us with information about living things that inhabited the earth years ago."
- Life science standards in the lower and middle grades were strengthened and made more specific to develop concepts of evolution, including adaptation, heredity, and comparison of organisms.
- Based on significant feedback from teachers, the focus on plants and animals in grades 6-8 was extended to include a standard that specified the human organism as a set of systems that interact with each other.

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- The description of the taxonomic system was sharpened by including in the standards for grades 6-8 the classification of organisms into "the *currently recognized* kingdoms."
- At the high school level, we recognized the growing importance of molecular biology by adding the standard asking students to "Describe the processes of replication, transcription, and translation and how they relate to each other in molecular biology."
- In the physics standards, plasma was specified as the fourth state of matter.

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

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

Sincerely,

David P. Driscoll
Commissioner of Education

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Acknowledgments

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

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

Introduction

The Massachusetts Science and Technology/Engineering Curriculum Framework is one of seven curriculum frameworks that advance Massachusetts's educational reform in learning, teaching, and assessment. It was created and has been revised by teachers and administrators of science and technology/engineering programs in prekindergarten through grade 12 school districts, by college and university professors, and by engineers and scientists in the various domains working with staff from the Department of Education. Its purpose is to guide teachers and curriculum coordinators about what content should be taught from PreK through high school.

Organization of the Framework

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

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

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

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

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

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

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Development of the standards

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

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

The draft produced by the revision panel was released for public comment in August 1999. Based on comments on this draft from science and technology/engineering teachers and other educators, further revisions were made, particularly at the high school level. Groups of high school science teachers in each domain of science developed a comprehensive set of standards for a course in each domain from which core standards were chosen for discipline-specific assessments. Groups of technology/engineering educators also contributed to the development of a comprehensive set of standards and core standards for the technology/engineering course at the high school level.

Inquiry and Experimentation

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

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

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

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

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

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

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

Skills of Inquiry

Grades PreK-2

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

Grades 3-5

- Ask questions and make predictions that can be tested.
- Select and use appropriate tools and technology (e.g., calculators, computers, balances, scales, meter sticks, graduated cylinders) in order to extend observations.
- Keep accurate records while conducting simple investigations or experiments.

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- Conduct multiple trials to test a prediction. Compare the result of an investigation or experiment with the prediction.
- Recognize simple patterns in data and use data to create a reasonable explanation for the results of an investigation or experiment.
- Record data and communicate findings to others using graphs, charts, maps, models, and oral and written reports.

Grades 6-8

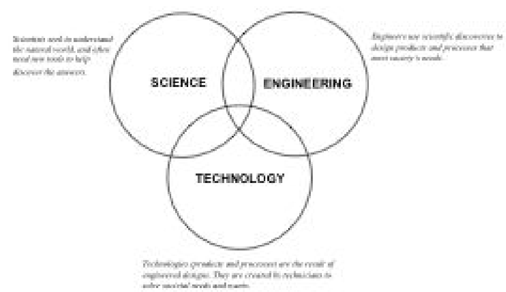
- Formulate a testable hypothesis.
- Design and conduct an experiment specifying variables to be changed, controlled, and measured.
- Select appropriate tools and technology (e.g., calculators, computers, thermometers, meter sticks, balances, graduated cylinders, and microscopes), and make quantitative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

Strand 4: Technology/Engineering

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

Technology/engineering works in conjunction with science to expand our capacity to understand the world. For example, scientists and engineers apply scientific knowledge of light to develop lasers and fiber optic technologies and other technologies in medical imaging. They also apply this scientific knowledge to develop such modern communications technologies as telephones, fax machines, and electronic mail.

The Relationship Among Science, Engineering, and Technology



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

Technologies developed through engineering include the systems that provide our houses with water and heat; roads, bridges, tunnels, and the cars that we drive; airplanes and spacecraft; cellular phones, televisions, and computers; many of today's children's toys; and systems that create special effects in movies. Each of these came about as the result of recognizing a need or problem and creating a technological solution. Figure 1 on page 53 shows the steps of the engineering design process. Beginning in the early grades and continuing through high school, students carry out this design process in ever more sophisticated ways. As they gain more experience and knowledge, they are able to draw on other disciplines, especially mathematics and science, to understand and solve problems.

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

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

In grades 6-8, students pursue engineering questions and technological solutions that emphasize research and problem solving. They identify and understand the five elements of a technology system (goal, inputs, processes, outputs, and feedback). They acquire basic skills in the safe use of hand tools, power tools, and machines. They explore engineering design; materials, tools, and machines; and communication, manufacturing, construction, transportation, and bioengineering technologies. Starting in these grades and extending through grade 10, the topics of power and energy are incorporated into the study of most areas of technology. Students integrate knowledge they acquired in their mathematics and science curricula to understand the links to engineering. They achieve a more advanced level of skill in engineering design by learning to conceptualize a problem, design prototypes in three dimensions, and use hand and power tools to construct their prototypes, test their prototypes, and make modifications as necessary. The culmination of the engineering design experience is the development and delivery of an engineering presentation.

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

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

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

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

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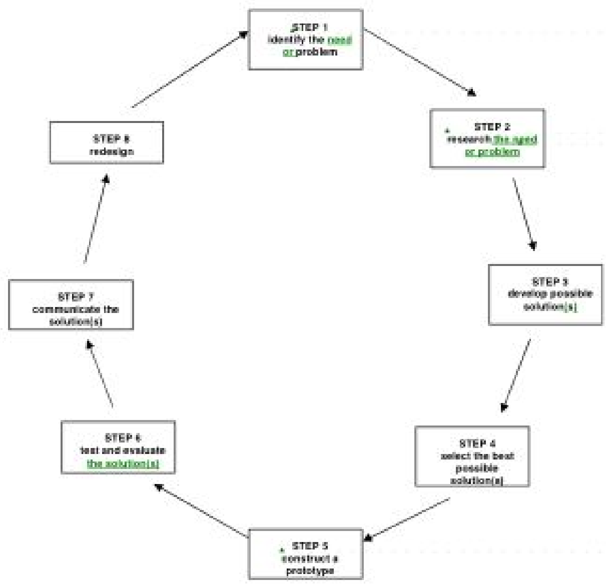
Figure 1
Steps of the Engineering Design Process



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1. Identify the need or problem
2. Research the need or problem
    - Examine current state of the issue and current solutions
    - Explore other options via the internet, library, interviews, etc.
3. Develop possible solution(s)
    - Brainstorm possible solutions
    - Draw on mathematics and science
    - Articulate the possible solutions in two and three dimensions
    - Refine the possible solutions
4. Select the best possible solution(s)
    - Determine which solution(s) best meet(s) the original requirements
5. Construct a prototype

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- Model the selected solution(s) in two and three dimensions

6. Test and evaluate the solution(s)
   - Does it work?
   - Does it meet the original design constraints?
7. Communicate the solution(s)
   - Make an engineering presentation that includes a discussion of how the solution(s) best meet(s) the needs of the initial problem, opportunity, or need
   - Discuss societal impact and tradeoffs of the solution(s)
8. Redesign
   - Overhaul the solution(s) based on information gathered during the tests and presentation

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Technology/Engineering Learning Standards

Please note: Suggested extensions to learning in technology/engineering for grades PreK -5 are listed with the science learning standards. See pages 12-21 (earth and space science), 31-38 (life science), and 46-51 (physical sciences).

Grades PreK-2

1. Materials and Tools

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

1.1 Identify and describe characteristics of natural materials (e.g., wood, cotton, fur, wool) and human-made materials (e.g., plastic, Styrofoam).

1.2 Identify and explain some possible uses for natural materials (e.g., wood, cotton, fur, wool) and human-made materials (e.g., plastic, Styrofoam).

1.3 Identify and describe the safe and proper use of tools and materials (e.g., glue, scissors, tape, ruler, paper, toothpicks, straws, spools) to construct simple structures.

2. Engineering Design

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

2.1 Identify tools and simple machines used for a specific purpose, e.g., ramp, wheel, pulley, lever.

2.2 Describe how human beings use parts of the body as tools (e.g., teeth for cutting, hands for grasping and catching), and compare their use with the ways in which animals use those parts of their bodies.

Grades 3-5

1. Materials and Tools

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

1.1 Identify materials used to accomplish a design task based on a specific property, i.e., weight, strength, hardness, and flexibility.

1.2 Identify and explain the appropriate materials and tools (e.g., hammer, screwdriver, pliers, tape measure, screws, nails, and other mechanical fasteners) to construct a given prototype safely.

1.3 Identify and explain the difference between simple and complex machines, e.g., hand can opener that includes multiple gears, wheel, wedge gear, and lever.

2. Engineering Design

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

2.1 Identify a problem that reflects the need for shelter, storage, or convenience.

2.2 Describe different ways in which a problem can be represented, e.g., sketches, diagrams, graphic organizers, and lists.

2.3 Identify relevant design features (e.g., size, shape, weight) for building a prototype of a solution to a given problem.

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2.4 Compare natural systems with mechanical systems that are designed to serve similar purposes, e.g., a bird's wings as compared to an airplane's wings.

Grades 6-8

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

1. Materials, Tools, and Machines

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

1.1 Given a design task, identify appropriate materials (e.g., wood, paper, plastic, aggregates, ceramics, metals, solvents, adhesives) based on specific properties and characteristics (e.g., weight, strength, hardness, and flexibility).

1.2 Identify and explain appropriate measuring tools, hand tools, and power tools used to hold, lift, carry, fasten, and separate, and explain their safe and proper use.

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

Suggested Learning Activities

- Conduct tests for weight, strength, hardness, and flexibility of various materials, e.g., wood, paper, plastic, ceramics, metals. (1.1)
- Design and build a catapult that will toss a marshmallow the farthest. (1.1, 1.2, 1.3)
- Use a variety of hand tools and machines to change materials into new forms through forming, separating, and combining processes, and processes that cause internal change to occur. (1.2)

2. Engineering Design

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

2.1 Identify and explain the steps of the engineering design process, i.e., identify the need or problem, research the problem, develop possible solutions, select the best possible solution(s), construct a prototype, test and evaluate, communicate the solution(s), and redesign.

2.2 Demonstrate methods of representing solutions to a design problem, e.g., sketches, orthographic projections, multiview drawings.

2.3 Describe and explain the purpose of a given prototype.

2.4 Identify appropriate materials, tools, and machines needed to construct a prototype of a given engineering design.

2.5 Explain how such design features as size, shape, weight, function, and cost limitations would affect the construction of a given prototype.

2.6 Identify the five elements of a universal systems model: goal, inputs, processes, outputs, and feedback.

Suggested Learning Activities

- Given a prototype, design a test to evaluate whether it meets the design specifications. (2.1)

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- Using test results, modify the prototype to optimize the solution, i.e., bring the design closer to meeting the design constraints. (2.1)
- Communicate the results of an engineering design through a coherent written, oral, or visual presentation. (2.1)
- Develop plans, including drawings with measurements and details of construction, and construct a model of the solution, exhibiting a degree of craftsmanship. (2.2)

3. Communication Technologies

Broad Concept: Ideas can be communicated though engineering drawings, written reports, and pictures.

3.1 Identify and explain the components of a communication system, i.e., source, encoder, transmitter, receiver, decoder, storage, retrieval, and destination.

3.2 Identify and explain the appropriate tools, machines, and electronic devices (e.g., drawing tools, computer-aided design, and cameras) used to produce and/or reproduce design solutions (e.g., engineering drawings, prototypes, and reports).

3.3 Identify and compare communication technologies and systems, i.e., audio, visual, printed, and mass communication.

3.4 Identify and explain how symbols and icons (e.g., international symbols and graphics) are used to communicate a message.

4. Manufacturing Technologies

Broad Concept: Manufacturing is the process of converting raw materials (primary process) into physical goods (secondary process), involving multiple industrial processes, e.g., assembly, multiple stages of production, quality control.

4.1 Describe and explain the manufacturing systems of custom and mass production.

4.2 Explain and give examples of the impacts of interchangeable parts, components of mass-produced products, and the use of automation, e.g., robotics.

4.3 Describe a manufacturing organization, e.g., corporate structure, research and development, production, marketing, quality control, distribution.

4.4 Explain basic processes in manufacturing systems, e.g., cutting, shaping, assembling, joining, finishing, quality control, and safety.

5. Construction Technologies

Broad Concept: Construction technology involves building structures in order to contain, shelter, manufacture, transport, communicate, and provide recreation.

5.1 Describe and explain parts of a structure, e.g., foundation, flooring, decking, wall, roofing systems.

5.2 Identify and describe three major types of bridges (e.g., arch, beam, and suspension) and their appropriate uses (e.g., site, span, resources, and load).

5.3 Explain how the forces of tension, compression, torsion, bending, and shear affect the performance of bridges.

5.4 Describe and explain the effects of loads and structural shapes on bridges.

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Suggested Learning Activities

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

6. Transportation Technologies

Broad Concept: Transportation technologies are systems and devices that move goods and people from one place to another across or through land, air, water, or space.

6.1 Identify and compare examples of transportation systems and devices that operate on each of the following: land, air, water, and space.

6.2 Given a transportation problem, explain a possible solution using the universal systems model.

6.3 Identify and describe three subsystems of a transportation vehicle or device, i.e., structural, propulsion, guidance, suspension, control, and support.

6.4 Identify and explain lift, drag, friction, thrust, and gravity in a vehicle or device, e.g., cars, boats, airplanes, rockets.

Suggested Learning Activities

- Design a model vehicle (with a safety belt restraint system and crush zones to absorb impact) to carry a raw egg as a passenger. (6.1)
  - Design and construct a magnetic levitation vehicle as used in the monorail system. Discuss the vehicle's benefits and trade-offs. (6.2)
  - Conduct a group discussion of the major technologies in transportation. Divide the class into small groups and discuss how the major technologies might affect future design of a transportation mode. After the group discussions, the students draw a design of a future transportation mode (car, bus, train, plane, etc.). The students present their vehicle design to the class, including a discussion of the subsystems used. (6.1, 6.3)

7. Bioengineering Technologies

Broad Concept: Bioengineering technologies explore the production of mechanical devices, products, biological substances, and organisms to improve health and/or contribute improvement to our daily lives.

7.1 Explain examples of adaptive or assistive devices, e.g., prosthetic devices, wheelchairs, eyeglasses, grab bars, hearing aids, lifts, braces.

7.2 Describe and explain adaptive and assistive bioengineered products, e.g., food, bio-fuels, irradiation, integrated pest management.

Suggested Learning Activities

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

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What It Looks Like in the Classroom

Local Wonders

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

Technology/Engineering Grades 6-8

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

After building newspaper towers and talking about structures and foundations, fifth and sixth graders at the Watertown, Massachusetts Boys and Girls Club brainstormed a list of interesting structures in their town. They selected St. Patrick's, an elaborate church across the street from the clubhouse. The children brainstormed questions about their local wonder. Those with an engineering focus included: When was it built? How long did the construction take? Who built it? What is it made of? Why did the builders choose that material? What is underneath the building? What holds it up? What keeps it from falling down? How was it built? Were there any problems during construction and how were they solved? Questions with a social/environmental focus included: Why was it built? What did the area look like before it was built?

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

Students can use the following method to estimate the size of a large structure. First, measure a friend's height. Have your friend stand next to the structure, while you stand a distance away (across the street, for instance). Close one eye and use your fingers to "stack" your friend's height until you reach the top of the structure. Multiply the number of times you stacked your friend by his/her height to find the total estimated height of the structure.

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The outline of the final report may look like this:

I. Name of group submitting report
II. Name and description of structure (identify the type of structure, e.g., bridge, skyscraper, and decribe and explain its parts)
III. Location
IV. Approximate date structure was completed
V. Approximate size
VI. Why we chose this particular local wonder
VII. What's important about our local wonder
VIII. Things we learned about our local wonder (include information such as type of construction, engineering design concepts, and forces acting on the structure)
IX. Interesting facts about our local wonder

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

Assessment Strategies

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

Note: The applicable standards may vary depending upon the type of structure selected.
Engineering Design Learning Standards

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

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Construction Technologies Learning Standards

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

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James A. Caradonio, Ed.D.
Superintendent

May 29, 2002

Denise W. Nicoletti, Ph.D.
Assoc. Professor of Electrical and Computer Engineering
WPI
100 Institute Road
Worcester MA 01609

Dear Prof. Nicoletti,

The Worcester Public Schools (WPS) wholeheartedly endorses "K-6 Gets a Piece of the P.I.E.E.," WPI's grant proposal to the National Science Foundation for GK-12 Teaching Fellows. Our enthusiasm for this current initiative comes from a long and very fruitful relationship with WPI. As WPS Superintendent, I am especially pleased that you will be a PI in this initiative, given your ongoing success with our middle school girls in the field of engineering. The opportunity now to bring engineering to elementary school teachers is both timely and exciting.

We have selected two schools to begin the program, Elm Park Community School, a long-time neighborhood partner to WPI, and Midland Street School, just a short walk from the WPI campus. The principals of both schools are eager to get their teachers involved and to see their students gain from this experience.

Demographic information for these two schools is fairly representative of our school district, which totals 26,000 students:

School	Enrollment	Male	Female	Minority	African American	Latino	FRL*
Elm Park	468	270	198	58.8%	17.0%	28.8%	87.8%
Midland St.	297	151	146	39.4%	11.0%	20.0%	42.4%

*Free and Reduced Price Lunch

Even before the State adopted its new Science and Technology/Engineering Curriculum Framework (2001), the Worcester Public Schools took the lead in Massachusetts by creating the first K-12 Engineering Pipeline Collaborative (EPiC). Now starting its third year in the WPS Doherty Quadrant, EPiC has developed an "Academy of Engineering" at Doherty High School, a "Pre-Engineering Cluster" at Forest Grove Middle School, and professional development for the elementary level focused on using engineering-type activities to enhance the science curriculum.

The major goal of this massive undertaking is to increase the academic achievement of our large, diverse student population by addressing the content in the "Science and Technology/Engineering" Curriculum Framework through access to more challenging courses, academic support in the areas of mathematics and science, exciting applications and curriculum units, and more exposure to careers in the engineering field.

We have already committed significant resources for building rehabilitation, technology, curriculum and professional development. This has been accomplished through the coordination of various funding streams, including our foundation budget, a "career majors" grant from the Massachusetts Department of Education, initial funding from the UMass/Raytheon K-16 Engineering Pipeline Collaborative, and a recent gift from Verizon to provide engineering mentors for middle school girls. These funds total in excess of $800,000, allowing us to put the following structures in place:

"EPiC" The Engineering Pipeline Collaborative	Board of Directors
"Academy of Engineering Doherty High School	Grades 9, 10, 11
"Pre-Engineering Cluster" Forest Grove Middle School	Grade 8

It is at the elementary level that we are sorely lacking. K-6 teachers are trained as generalists, and few have concentrations in math or science. They would have their content knowledge increased and their confidence boosted if they could share their teaching with WPI Fellows. Teaching Fellows would benefit from WPS teachers' experience in the classroom, and might choose to become K-12 teachers themselves, at a time when school systems nationwide are hungry for them.

The Worcester Public Schools is truly committed to expanding "EPiC" in the Doherty Quadrant. To accomplish that end, we will need to build capacity in our elementary "feeder" schools. This NSF grant will be a major factor in helping us to reach this goal.

Sincerely,

James A. Caradonio

James A. Caradonio, Ed.D.
Superintendent, Worcester Public Schools

WPI

Electrical and Computer Engineering Department
100 Institute Road • Worcester, MA 01609-2280
Phone 508-831-5231 • Fax 508-831-5491 • http://www.wpi.edu/

June 3, 2002

To Whom It May Concern:

As Associate Department Head and Graduate Coordinator for the Electrical and Computer Engineering (ECE) Department at WPI, I fully support the initiatives described in the proposal to the NSF Graduate Teaching Fellows in K-12 Education program. It would be appropriate and welcome for ECE graduate students to receive support through this program while pursuing their degree.

I know from conversations with current ECE graduate students that at least one to two students each year have expressed interest in developing their skills in teaching while attaining their degree. Because of this, I am optimistic that we would find good candidates for this fellowship.

Sincerely,

F A Looft

Fred Looft, Ph.D.
Professor

WPI

DEPARTMENT OF MATHEMATICAL SCIENCES
WORCESTER POLYTECHNIC INSTITUTE
WORCESTER, MA 01609 – 2280

Homer F. Walker, Professor and Department Head 508-831-5241 walker@wpi.edu Fax: 508-831-5824

May 30, 2002

To whom it may concern:

I am delighted to lend my strong support to the initiatives described in the proposal to the NSF Graduate Teaching Fellows in K-12 Education program. Support through this program for Mathematical Sciences graduate students would be most appropriate and welcome.

We should be able to find easily several well-qualified students who would be very worthy of support. I am especially enthusiastic about the possibility of supporting students in our Master of Mathematics for Educators program. This program, which currently has about 20 students in it, is a *mathematics* degree (not an education degree) especially oriented toward students who intend to pursue careers in K-12 teaching.

This support would also enable an exciting opportunity for students to become involved in our new Mathematics in Industry Workshop for High School Teachers. This will bring about 80 high school teachers to campus for one week in each of the next three summers. During their stay, they will work with faculty, industrial mathematicians and students to find effective ways to use real-world problems to motivate high school students, in particular women and underrepresented minorities, to pursue careers in mathematics, engineering, information technology or finance/economics.

Sincerely,

Homer F. Walker
Mathematical Sciences Department Head

XI
D.
Assessment Form

Lesson Plan Assessment Form

PIEE Student________________________ Date______________

School____________ Grade Level____ Name of Lesson________________________

Date of Implemented Lesson____________ Name of Evaluator____________________

WPS Benchmarks Implemented____
Assessment Key:
0=Strongly Disagree 1=Disagree 2=Agree 3=Strongly Agree
Place an X in the designated boxes with optional comments.

Do you agree that..?	**0**	**1**	**2**	**3**	**NA**	**Comments**
The lesson plan was appropriate for the grade level?						
The lesson plan encouraged children's original ideas?						
The students understood the information that was instructed?						
The materials used were appropriate? (e.g. cost, reusability, easy to use)						
The lesson plan followed the WPS Benchmarks?						
The PIEE student's parcticipation/instruction was useful?						
The overall quality of the lesson plan was excellent?						

What was the strongest component of this lesson? Please give an example of why this quality was important.

What was the weakest component of this lesson and what would you change to make it better so that it can be used in the future?

Any additional comments?

Lesson Plan Assessment Form Grading Rubric

Name:________________________________ **Date:___________________**

Instructions:
Take the total number of points earned and divide it by the total number of possible points minus the possible points from the NA boxes. Then multiply that number by 100.

Example:
Total possible points: 24
Number of NA's: 2
24-2=22
Total points earned: 17

17/22 X 100= about 77 %

You received __________ % on your evaluation

Do you agree with your score and why do you feel this way?

What changes could you make to better this lesson and how would those changes make an impact on the outcome?

Learning from your experience with this lesson, what will you do in your future lessons to better their quality?