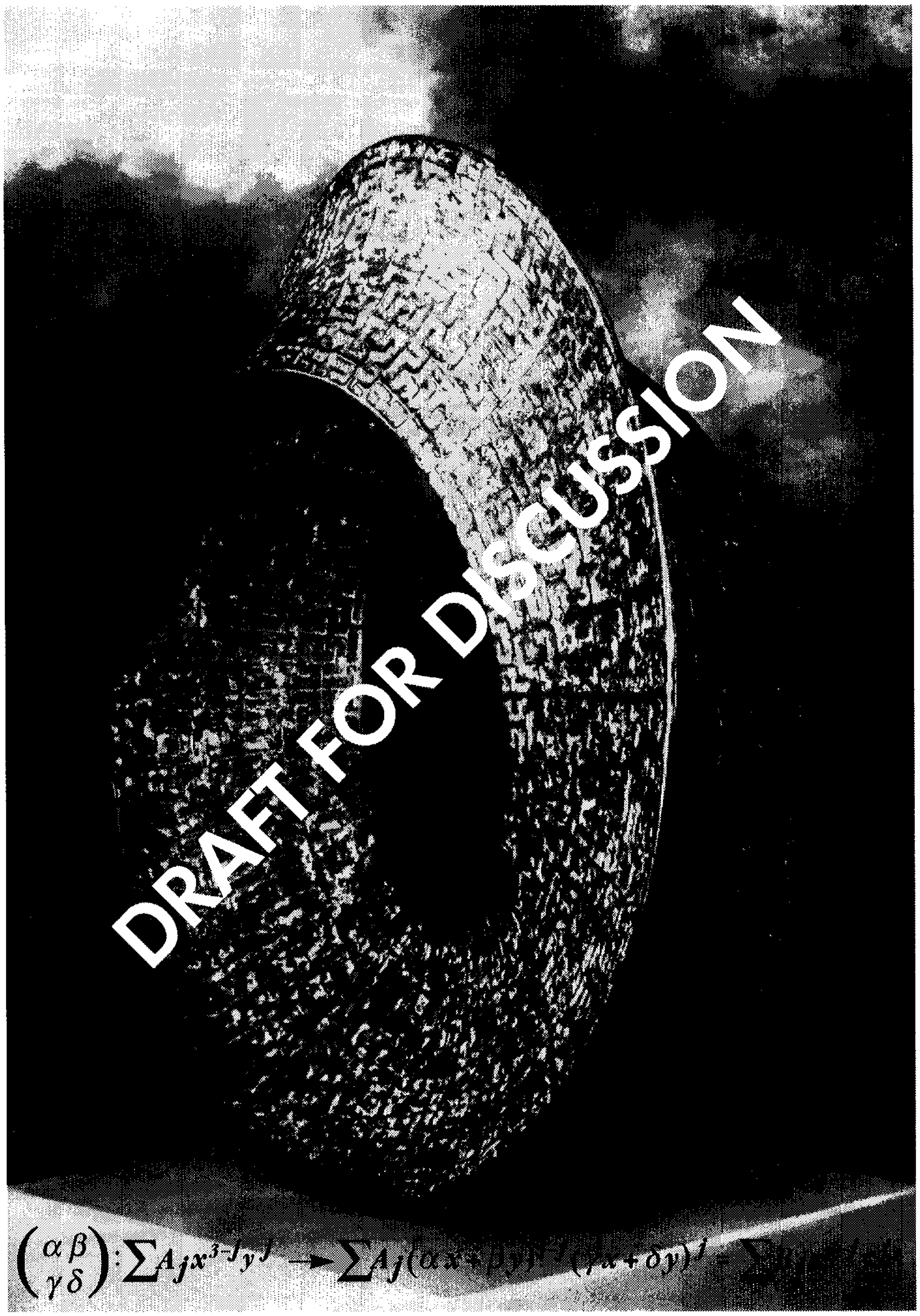
CURRICULUM INSTRUCTION



AND ASSESSMENT

FRAMEWORK FOR MATHEMATICS, SCIENCE AND TECHNOLOGY

Revised March 5, 1994
Draft for Distribution

The attached material is still being discussed by the Board of Regents and does not represent Regents Policy

The University of the State of New York
The State Education Department

NEW YORK
THE STATE OF LEARNING

THE STATE EDUCATION DEPARTMENT / THE UNIVERSITY OF THE STATE OF NEW YORK / ALBANY, N.Y. 12234

PRESIDENT OF THE UNIVERSITY
AND COMMISSIONER OF EDUCATION
THE NEW YORK STATE EDUCATION DEPARTMENT
ALBANY, NEW YORK 12234

April 1994

To All Interested Parties:

This is a draft copy of a proposed Curriculum Framework for Mathematics, Science, and Technology. It has been developed by the Curriculum and Assessment Committee for Mathematics, Science, and Technology and by State Education Department staff. It is now being distributed to educators and to the public for review and comment.

The purpose of curriculum frameworks is to inform local curriculum, assessment, and staff development. The frameworks specify in broad terms the skills and knowledge that students should acquire, set forth standards of curriculum content and student performance, and provide illustrations of effective teaching and assessment practice. They provide guidance for the development of local curricula, defining a common core of study but leaving room for local imagination and initiative. They are much more detailed than the Regents Goals for Elementary and Secondary Education, but less specific than the advisory syllabi and instructional guides traditionally published by the Department. (The Department will continue to update and provide this optional material, along with information about other resources that may be helpful in meeting the expectations of the frameworks.)

This Mathematics, Science, and Technology Framework reflects substantial thought and discussion by many informed people, but the material has not yet been approved by the Regents and does not represent Regents policy. During the coming weeks there will be opportunities across the State for interested parties to meet and comment on the Report. We welcome your written comments as well. Such commentary will help to shape the final products of this initiative, and will ground the work in the knowledge and experience of professionals and "consumers" of the public education system.

We especially need to know your answers to questions like these:

- Is the framework specific enough to provide useful guidance for local curriculum-making?
- Is the framework general enough to permit local variation and adaptation?
- Does the framework try to do too much? Does it do too little?

- Are the performance standards contained in the framework too demanding? Not demanding enough?

As we develop the curriculum frameworks and the revised assessment system, we will be guided by certain operating principles:

1) The purpose of revising New York State's assessment program is to help raise the standards and quality of teaching and learning in schools across the State.

2) The revised assessment measures and practices will be benchmarked to the highest standards and best practices nationally and internationally.

3) We will eliminate or reduce no standard now existing unless and until a higher standard is put in place. We will eliminate or water down no test or other assessment now existing unless or until a more demanding and effective set of assessments is put in place.

4) The proposed revisions will be subjected to extensive review and trial use, and will be revised wherever appropriate, before taking full effect.

5) The revised assessment program will be phased in during the coming five years, to allow time for a planned transition from existing curricular and assessment practices to the new ones.

6) Teachers, administrators, and other relevant parties will receive training and ongoing support in the use of the new assessments.

I invite your comment upon the contents of this document. Meanwhile, I thank the members of the Mathematics, Science, and Technology Committee for this exciting proposal. I predict that it will have lasting, constructive value for teaching and learning in our State.

Sincerely,

Thomas Sobol

Thomas Sobol

CURRICULUM, INSTRUCTION, AND ASSESSMENT

FRAMEWORK

FOR MATHEMATICS, SCIENCE, AND TECHNOLOGY

NEW YORK STATE EDUCATION DEPARTMENT

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Previous versions of this framework used the term outcomes for the statements of proposed student learning. To avoid confusion with other interpretations of the term *outcome* and to be consistent with the terminology being used in national educational projects, this framework has been edited to use the terms *content standards* and *performance standards*.

CONTENTS

A response form for readers is on page 95. The next version of this document will reflect comments from those who respond.

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CHAPTER I: THE FOUNDATION FOR THE MATHEMATICS, SCIENCE, AND TECHNOLOGY FRAMEWORK

New York State's educational system must change to meet the demands of the twenty-first century. Students need to be prepared for a world that is rapidly changing, rich in information, competitive yet interdependent, technologically complex, and culturally diverse.

A New Compact for Learning, approved in 1991 by the Board of Regents, provides a rationale for systematic change and a vision for New York State's educational reform. Central to the vision described in the *Compact* is local development of curriculum, instruction, and assessment that results in student achievement of specific standards.

The New York State Curriculum and Assessment Council has defined ***content standards*** **as "the knowledge, skills, and understandings that individuals can and do habitually demonstrate over time as a consequence of instruction and experience."** The approach adopted in the *Compact* calls for educators and communities to have more flexibility than ever before in deciding how to help all students achieve these standards.

The mathematics, science, and technology standards are fully described in this curriculum framework. **A *curriculum framework* is a broad description of the principles, topics, and modes of inquiry or performance in a discipline which provides the basic structure of ideas upon which a curriculum is based. A stepping stone between standards and curriculum.** The mathematics, science, and technology framework provides direction for schools and districts as they construct a curriculum that addresses the needs of their students. Local planners have the flexibility to design interdisciplinary work; to schedule the work of students and staff and to organize the school day, week, and year; to use a variety of strategies to build knowledge and skills, varying with the learner, but directed purposefully toward achieving the desired results of learning.

The standards in this framework apply to all students, regardless of their experiential background, capabilities, developmental and learning differences, interests, or ambitions. A classroom typically contains students with a wide range of abilities who may pursue multiple pathways in order to learn effectively, participate meaningfully, and work towards attaining the standards. Students with learning problems or disabilities, as well as gifted students, may need accommodations or adaptations of instructional strategies and materials in order to enhance their learning and/or to adjust for their learning capabilities.

In order for the mathematics, science, and technology standards to be achieved, the following conditions must exist:

- Students should be involved with each other, with educators, with the community and the workplace in: *doing, thinking, observing, designing, constructing, synthesizing, analyzing,* and *experiencing.*

- Skills, knowledge, and values of teachers should be enhanced through ongoing staff development.

- Content and process should be contemporary.

- Resources should be rich and diverse.

- The course curriculum should be connected to the total school curriculum.

- Multiple pathways to appropriate learning and mastery for all students should be provided.

Students at any level bring a number of ideas concerning natural phenomena, mathematical concepts and relationships, and design processes and products to the classroom. New learning in mathematics, science, and technology builds on such prior knowledge if it is to be meaningful and retained by students. While the construction of new and expanded meanings is a highly personal and individual process, the sharing and negotiation of ideas among students and between students and teachers enhances understanding. As learners build conceptual hierarchies and networks based on previous knowledge and experiences, they are able to employ reasoning skills such as interpretation, analysis, application, and synthesis, along with skills relating to the collection and organization of information.

This constructivist theory of learning has been shown to have broad power in explaining why such instructional strategies as cooperative learning, integrated learning, problem solving, and inquiry approaches promote meaningful learning. The challenge for mathematics, science, and technology teachers is to skillfully use a variety of proven strategies, techniques, and tools to facilitate the active construction of multiple aspects of knowledge and development of a variety of skills on the part of learners.

Besides articulating desired standards and explaining what students will gain by achieving them, the mathematics, science, and technology framework describes the key concepts and key competencies related to each standard. **The *key concepts* state major ideas—what all students should know. The *key competencies* state important skills—what students should be able to do. An *area of study* is a small number of related key concepts and competencies that form a set of powerful ideas. Together, related areas of study constitute a discipline.**

Some competencies are skills particular to mathematics, science, and technology. Others are central to learning in all disciplines, and are important for successful participation in all areas of life. The latter have been defined in a number of studies.[1] The emphasis throughout these studies of essential skills and dispositions has been on setting a direction in education that will better enable students to develop critical employment and life skills, prepare for careers of the future, effectively balance work and family life, and develop the abilities necessary to enjoy a full and productive life.

***Performance standards* are described for three levels, designated as elementary, intermediate, and commencement. Each performance standard is compromised of *performance indicators* that specify what students should know and be able to do as they progress toward achieving the standards.** The performance indicators focus on student progression from level to level, showing that students are progressively engaged

[1] The Secretary's Commission on Achieving Necessary Skills, *What Work Requires of Schools* (Washington, DC: U.S. Department of Labor, June 1991); the New York State Education Department report, "Preparing Youth for the Workforce: An Integrated Approach"; the Hudson Institute report, *Workforce 2000: Work and Workers for the 21st Century*; the State University of New York's Task Force on College Entry-Level Knowledge and Skills report, "SUNY 2000: College Expectations"; and the Center for Governmental Services publication, *Building Public-Private Partnerships.*

in higher levels of complex thinking, a wider range of subject matter, and more independent learning. Elementary, intermediate, and commencement suggest appropriate indicators of performance for assessing students at the end of elementary, middle, and high school levels. The intent is to ensure continuity; that is, that skills and major areas of content should be addressed continuously as students move from level to level. These levels do not correspond with age or grade levels, but rather with the achievement of the standard.

For example, a ninth grade student with limited English proficiency who has not been exposed to a specific aspect of curriculum content in science may be at the same point on the continuum as an elementary school child gaining initial exposure to the same content. The ninth grader and the elementary student may be placed in different grades in the educational system, but they might be at the same point in progression for a particular standard.

***Performance tasks* are what students might do to show that they have acquired the knowledge and skills that performance indicators describe.** Performance tasks are intended to integrate performance indicators from a number of key concepts and competencies. These performance indicators might be drawn from within a standard, from across standards, and from across disciplines. Illustrative examples of performance tasks that might be used to show student attainment of key concepts and key competencies are included at the end of Standard 1. Teachers and educators responsible for curriculum coordination are encouraged to contribute examples of performance tasks for all of the standards.

Regents Goals for Elementary, Middle, and Secondary School Students

As part of the implementation of *A New Compact for Learning*, in 1991 the Board of Regents revised the Regents Goals for Elementary, Middle, and Secondary School Students. The updated goals have an increased emphasis on the application of information, on the varied roles of adults and family members in society, and on critical employment skills. The responsibility for achieving the goals is shared by the State, local community, school, family, and individual student. The Regents Goals are the basis for the development of standards.

The Regents Goals are the basis for the development of standards.

The Regents Goals are the same for all students. They represent expectations for students, with the understanding that all students are not the same. Each student has different talents, developmental and learning differences, abilities, and interests. Schools must recognize and attend to these differences in order to provide an educational experience that enables all students to succeed.

Goal 1: Each student will master communication and computation skills as a foundation to:

1.1 Think logically and creatively
1.2 Apply reasoning skills to issues and problems
1.3 Comprehend written, spoken, and visual presentations in various media
1.4 Speak, listen to, read, and write clearly and effectively in English
1.5 Perform basic mathematical calculations
1.6 Speak, listen to, read, and write in at least one language other than English
1.7 Use current and developing technologies for academic and occupational pursuits
1.8 Determine what information is needed for particular purposes and be able to use libraries and other resources to acquire, organize, and use that information for those purposes

Goal 2: Each student will be able to apply methods of inquiry and knowledge learned through the following disciplines and use the methods and knowledge in interdisciplinary applications:

2.1 English language arts
2.2 Science, mathematics, and technology
2.3 History and social science
2.4 Arts and humanities
2.5 Language and literature in at least one language other than English
2.6 Technological and occupational studies
2.7 Physical education, health, and home economics

Goal 3: Each student will acquire knowledge, understanding, and appreciation of the artistic, cultural, and intellectual accomplishments of civilization, and develop the skills to express personal artistic talents. Areas include:

3.1 Ways to develop knowledge and appreciation of the arts
3.2 Aesthetic judgments and the ability to apply them to works of art
3.3 Ability to use cultural resources of museums, libraries, theaters, historic sites, and performing arts groups
3.4 Ability to produce or perform works in at least one major art form
3.5 Materials, media, and history of major art forms
3.6 Understanding of the diversity of cultural heritages

Goal 4: Each student will acquire and be able to apply knowledge about political, economic, and social institutions and procedures in this country and other countries. Included are:

4.1 Political, economic, and social processes and policies in the United States at national, State, and local levels
4.2 Political, economic, and social institutions and procedures in various nations; ability to compare the operation of such institutions; and understanding of the international interdependence of political, economic, social, cultural, and environmental systems
4.3 Roles and responsibilities the student will assume as an adult, including those of parent, home manager, family member, worker, learner, consumer, and citizen
4.4 Understanding of the institution of the "family," respect for its function, diversity, and variety of form, and the need to balance work and family in a bias-free democratic society

Goal 5: Each student will respect and practice basic civic values and acquire and use the skills, knowledge, understanding, and attitudes necessary to participate in democratic self-government. Included are:

5.1 Understanding and acceptance of the values of justice, honesty, self-discipline, due process, equality, and majority rule with respect for minority rights
5.2 Respect for self, others, and property as integral to a self-governing, democratic society
5.3 Ability to apply reasoning skills and the process of democratic government to resolve societal problems and disputes

Goal 6: Each student will develop the ability to understand, appreciate, and cooperate with people of different race, sex, ability, cultural heritage, national origin, religion, and political, economic, and social background, and to understand and appreciate their values, beliefs, and attitudes.

Goal 7: Each student will acquire the knowledge of the ecological consequences of choices in the use of the environment and natural resources.

Goal 8: Each student will be prepared to enter upon post-secondary education and/or career-level employment at graduation from high school. Included are:

- 8.1 The interpersonal, organizational, and personal skills needed to work as a group member
- 8.2 The ability to use the skills of decision-making, problem-solving, and resource management
- 8.3 An understanding of ethical behavior and the importance of values
- 8.4 The ability to acquire and use the knowledge and skills to manage and lead satisfying personal lives and contribute to the common good

Goal 9: Each student will develop the knowledge, skills, and attitudes which will enhance personal life management, promote positive parenting skills, and will enable functioning effectively in a democratic society. Included are:

- 9.1 Self-esteem
- 9.2 Ability to maintain physical, mental, and emotional health
- 9.3 Understanding of the ill effects of alcohol, tobacco, and other drugs and of other practices dangerous to health
- 9.4 Basic skills for living, decision-making, problem solving, and managing personal resources to attain goals
- 9.5 Understanding of the multiple roles adults assume, and the rights and responsibilities of those roles
- 9.6 Basic skills for parenting and child development

Goal 10: Each student will develop a commitment to lifetime learning and constructive use of such learning, with the capacity for undertaking new studies, synthesizing new knowledge and experience with the known, refining the ability to judge, and applying skills needed to take ethical advantage of technological advances.

A New Compact for Learning

A New Compact for Learning represents a reconceptualization of education in New York State. It promotes partnerships between schools and the community in order to help all students attain the Regents Goals. The *Compact* is based on six key principles:

A New Compact for Learning promotes partnerships between schools and the community in order to help all students attain the Regents Goals.

1. All children can learn.

2. Focus on results.

3. Aim for mastery.

4. Provide the means.

5. Provide authority with accountability.

6. Reward success and remedy failure.

The *Compact* redefines the roles and responsibilities of the State and local school districts as they relate to curriculum, instruction, and assessment. The State's role is to work collaboratively with teachers, administrators, school boards, parents, and members of the community to transform the system of education.

Specific State responsibilities include:

- specifying the standards for elementary, middle, and secondary education;

- establishing performance criteria for the standards;

- assisting local schools and school districts in planning, developing, and implementing programs and practices to assure that all students achieve the standards;

- determining through a statewide assessment program if the standards are being achieved; and

- informing local schools and school districts about effective strategies relative to curriculum, instruction, and assessment.

The Mathematics, Science, and Technology Standards

The standards provide specificity beyond the Regents Goals.

Under the *Compact* the roles and responsibilities of local school districts also change. The State sets the goals and direction for education through standards, which provide specificity beyond the Regents Goals. To ensure that students achieve standards, local school districts will be given the authority and discretion to determine how best to organize and deliver their educational program.

Students must achieve the following standards in order to be literate in mathematics, science, and technology. An elaboration of the standards appears in Chapter III.

Standard 1
Analysis, Inquiry, and Design
Students will have knowledge, skills, and attitudes that empower them to use mathematical analysis, scientific inquiry, and engineering design, as appropriate, to pose questions, seek answers, and design solutions.

Standard 2
Systems
Students will acquire an understanding of the basic concepts of systems and their uses in the analysis and interpretation of interrelated phenomena in the real world, within the context of mathematics, science, and technology.

Standard 3
Information Resources
Students will use a full range of information systems, including computers, to process information and to network with different school and community resources, such as libraries, people, museums, business, industry, and government agencies.

Standard 4
Science
Students will demonstrate knowledge of science's contributions to our understanding of the natural world, including the physical setting, the living environment, and the human organism, and will be aware of the historical development of these ideas.

Standard 5
Technology
Students will acquire the knowledge and skills related to the tools, materials, and processes of technology to create products, services, and environments in the context of human endeavors such as bio-related technologies (agriculture, health), manufacturing, construction (shelter and other structures), transportation, and communication.

Standard 6
Mathematics

Students will understand and use basic mathematical ideas, including logic, number sense and numeration concepts, operations on numbers, geometry, measurement, probability and statistics, algebra, and trigonometry; and be familiar with their uses and application in the real world through problem solving, experimentation, validation, and other activities.

Standard 7
Connecting Themes

Students will understand the relationships among mathematics, science, and technology, identify common themes connecting them, and apply these themes to other areas of learning and performance.

Standard 8
Interdisciplinary Problem Solving

Students will apply the knowledge and thinking skills of mathematics, science, and technology to address real-life problems and make informed decisions.

Standard 9
Preparation for the Future

Students will develop habits of mind and social and career-related skills in mathematics, science, and technology education classes that will enable them to work productively with others, achieve success in a postsecondary school setting, enter the workplace prepared to achieve success in different jobs, and possess skills necessary for lifelong learning and continuing advancement.

*Rationale for the Mathematics, Science, and Technology Standards**

A revolution in public attitudes about mathematics, science, and technology education is under way. As both the cause and effect of the cries for change, the major national organizations representing mathematics, science, and technology education are now deeply engaged in rethinking what students should know and what they should be able to do—what the *standards* of education should be for all students.

The movement began with *Science for All Americans*, a comprehensive effort by the American Association for the Advancement of Science. Shortly afterward, NSTA (National Science Teachers Association) joined the call for a complete restructuring of the Scope, Sequence, and Coordination of traditional secondary school science. Both projects have involved scientists, engineers, and science educators. The latest efforts of AAAS, *Benchmarks*, involves the development and field testing of specific knowledge, skills, and beliefs about science and technology that are both useful and able to assist students in their personal development. The Conceptual Framework for Technology Education developed by the International Technology Education Association (ITEA) represents a national consensus relative to content and methodology in technology education. *Curriculum and Evaluation Standards for School Mathematics* was released in the spring of 1989. The *Standards*, developed under the auspices of the National Council of Teachers of Mathematics, established a broad framework to guide reform in mathematics education.

*Adapted from an article by Cecily Cannan Selby. Reprinted with permission from NSTA Publications, Oct. 1993, from *The Science Teacher*, National Science Teachers Association, 1840 Wilson Blvd., Arlington, VA 22201-3000, pp. 48-51. Dr. Selby is a member of the New York State Curriculum and Assessment Committee for Mathematics, Science, and Technology.

These messages echo the trailblazing recommendations in *Project Synthesis,* the massive collaboration between NSTA and the National Science Foundation that occurred during the late 1970s. The latest entry in the reform movement is from the National Academy of Sciences, which has initiated a comprehensive effort to identify standards for science teaching. Standards are being developed to provide frameworks for curriculum and assessment.

In New York State, the Curriculum and Assessment Committee for Mathematics, Science, and Technology has developed standards for the three disciplines. Composed primarily of teachers working together with some scientists, mathematicians, and engineers, the committee deliberated at length before writing its first standard:

> *Students will have knowledge, skills, and attitudes that empower them to use mathematical analysis, scientific inquiry, and engineering design, as appropriate, to pose questions, seek answers, and design solutions.*

The committee extends this standard by stating that mathematics, science, and technology are each distinguished by specific characteristics and processes. The three disciplines can be used separately, but more often they are used together. Students should understand the scope and limits of using these disciplines and should apply them when seeking solutions to problems. Students should know when these modes of inquiry and their tools are appropriate and when they are not, as well as what they can solve on their own and what questions require working with others. While mathematics, science, and technology are different, each can be enhanced through the others. These disciplines can also be integrated with other subjects in the curriculum; for example, statistics can be used in social studies, technology in art, and science in the history of ideas.

The committee further recognized another way of knowing and doing in its second standard:

> *Students will acquire an understanding of the basic concepts of systems and their uses in the analysis and interpretation of interrelated phenomena in the real world, within the context of mathematics, science, and technology.*

The first three standards deal with how we know: knowledge and skills for problem solving.

Through experience with ecology, hormone systems, thermostats, and human behavior, most of us understand something about systems thinking despite a lack of formal training in systems dynamics. It is essential to introduce systems analysis to students to enable them to transfer knowledge from one system to another by recognizing commonalities and by seeing interrelationships as well as objects, patterns of change, and static snapshots. For example, a person can understand ecological systems in terms of inputs, outputs, and feedback-control loops without knowing every chemical and biological reaction involved. And ecological systems can be compared to subway systems as well as cellular systems.

The third standard focuses on the vital role of information processing in learning and doing:

> *Students will use a full range of information systems, including computers, to process information and to network with different school and community resources, such as libraries, people, museums, business, industry, and government agencies.*

We recognize that today's student must be familiar with the latest technological tools (computers and telecommunications) that allow them to communicate, monitor, analyze, and process information. This includes networking with individuals as well as with libraries, businesses, museums, and other community resources.

With respect to what students should know, the committee drew upon the findings of the National Council of Teachers of Mathematics, **Project 2061** of AAAS, and the International Technology Education Association (ITEA) to generate the following list of standards:

> *Students will demonstrate knowledge of science's contributions to our understanding of the natural world, including the physical setting, the living environment, and the human organism, and will be aware of the historical development of these ideas.*
>
> *Students will acquire the knowledge and skills related to the tools, materials, and processes of technology to create products, services, and environments in the context of human endeavors such as bio-related technologies (agriculture, health) manufacturing, construction (shelter and other structures), transportation, and communication.*
>
> *Students will understand and use basic mathematical ideas, including logic, number sense and numeration concepts, operations on numbers, geometry, measurement, probability and statistics, algebra, and trigonometry; and be familiar with their uses and application in the real world through problem solving, experimentation, validation, and other activities.*

The middle three standards deal with what we know: what we have learned through these ways of knowing.

According to the reactions of teachers, the last three standards seem to be the most helpful in providing the answer to the question, "Why study mathematics, science, or technology education?":

> *Students will understand the relationships among mathematics, science, and technology, identify common themes connecting them, and apply these themes to other areas of learning and performance.*
>
> *Students will apply the knowledge and thinking skills of mathematics, science, and technology to address real-life problems and make informed decisions.*
>
> *Students will develop habits of mind and social and career-related skills in mathematics, science, and technology education classes that will enable them to work productively with others, achieve success in a postsecondary school setting, enter the workplace prepared to achieve success in different jobs, and possess skills necessary for lifelong learning and continuing advancement.*

The last three-standards answer, "why study mathematics, science, and technology education—what they can mean to our lives."

These statements of desired standards send a more honest, coherent, and realistic message than was previously available to parents, taxpayers, and administrators as to what science, technology, and mathematics really bring to the party. The adage, "Study science so you can make more informed decisions about health and environmental issues," is often cited today, but is the statement honest? Does receiving facts about acids, bases, or combustion necessarily lead to your using this information at the voting booth? To actively use hand-me-down information, students must value input from scientists, want to learn more, and see the interrelatedness of big ideas. Students need practice in recognizing and applying the natural connections among mathematics, science, and technology to personal and public problem solving.

To open the doors to science and technology for each learner, we need more valid views about what these subjects really are, about what makes inquiry scientific, about technology as more than applied science, and about mathematics as a living, creative partner in the endeavor.

We also need more valid views of how students learn and of new attitudes from teachers and professionals so that science education includes rather than excludes students. To quote a National Science Board report written in 1983:

> *. . . all students . . . can develop a useful understanding of mathematics, science and of technology if these subjects are appropriately introduced and skillfully taught at the elementary and secondary school levels.*

*A New Paradigm for Mathematics, Science, and Technology Education**

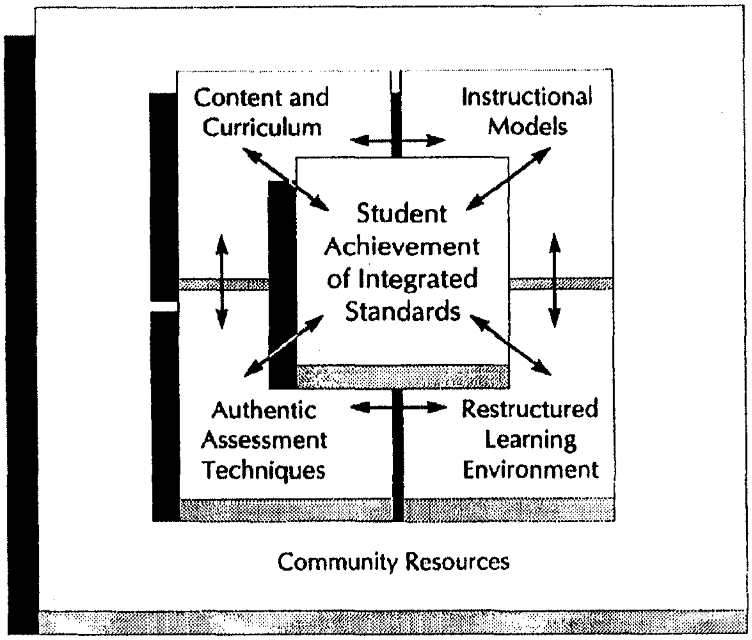
Mathematics, science, and technology, like all disciplines, are in the midst of a knowledge explosion. Technology is making it possible for students to access incredible amounts of information; encyclopedias are available on CD ROMS and Library of Congress holdings can be accessed through Internet. Students need to be engaged in learning activities that show them how to use these mind tools to access, analyze, and synthesize information.

A new kind of approach is needed to help students deal with the proliferation of knowledge. They should learn unifying concepts—the big ideas—that integrate knowledge. Besides decreasing the amount of content that has to be learned, the coming together of knowledge from different disciplines provides insights into the natural and technological world that goes beyond what can be learned in each discipline. The challenge is to design and implement an instructional program that helps students learn disciplinary concepts and skills in the context of unifying concepts and real-world systems and problems.

The new framework for mathematics, science, and technology education starts with broad statements of standards that satisfy both personal and societal needs. The standards state clearly how learning will prepare individuals to assume future adult roles. Performance indicators for elementary and intermediate grades provide feedback and guidance to make sure that students are progressing toward the standards. Assessment is based on the degree of progress that students are making toward understanding a specific area of knowledge.

In order to design an educational system that will enable students to achieve broad standards in a holistic learning environment, we need to determine the cornerstones on which our framework will sit. The new instructional structure will have many design features. To facilitate the discussion of the underlying assumptions of the new framework, four cornerstones have been identified: Content and Curriculum, Instructional Models, Authentic Assessment Techniques, and Restructuring of the Learning Environment. The educational system that is designed must be dynamic. There must be constant interaction between the broad standards and the four cornerstones, as depicted in the following view of our educational structure.

*Adapted from Thomas T. Liao, "Liberal Education in Mathematics, Science, and Technology: The Way Forward," *TIES Magazine* (Trenton State College and Drexel University), March/April 1993. pp. 38-41. Dr. Liao is co-chair of the New York State Curriculum and Assessment Committee for Mathematics, Science, and Technology.



Designed by Lesa Clark

Students are supported by the community, and then are able to become responsible and contributing members of it.

This diagram, besides showing the connections between the five major components of an education system, highlights the importance of using a total systems approach. In order for the system to provide effective instruction to all students, there must be continuing monitoring of whether all four cornerstones of our educational system are contributing toward the achievement of the standards.

Content and Curriculum
Today's mathematics, science, and technology curriculum is too discipline oriented and too much time is devoted to the learning of facts and fragmented bits of information and skills. The Mathematics, Science, and Technology Framework provides a model for designing curricula that better fit the needs of today's students and our modern technological society. Using this framework as a guide, local curriculum developers, within the context of both scientific and human considerations, should address the following:

*The Intrinsic Value of Knowledge—Does the proposed content present aspects of science, mathematics, and technology that are so important in human history or so pervasive in our culture that a general education would be incomplete without them?

*Utility—Will the proposed content—knowledge or skills—significantly enhance the graduate's long-term employment prospects? Will it be useful in making personal decisions?

*Social Responsibility—Is the proposed content likely to help citizens participate intelligently in making social and political decisions on matters involving science and technology?

*Philosophical Value—Does the proposed content contribute to the ability of people to ponder the enduring questions of humanity?

Childhood Enrichment—Will the proposed content enhance childhood?

Unifying Concepts—Are ideas such as modeling, systems analysis, equilibrium, and diversity studied in many contextual settings to help students make connections among seemingly unrelated content?

*From *Science for All Americans*, **Project 2061**, a long-term initiative of the American Association for the Advancement of Science, Inc., Washington, DC.

Instructional Models

The development of a student's natural interest in learning should be the goal of the selection and implementation of instructional models. This is an important step in the development of a positive attitude toward lifelong learning. We are interested in helping students think for themselves and come up with their own explanations of how systems in the natural and technological world behave. Students need to be involved in learning activities that provide opportunities for engagement, exploration, explanation, elaboration, and evaluation.

Restructuring the Learning Environment

It is important to redefine the roles of students, teachers, and administrators and the organization of their learning environments. The single most important factor in an individual's education is still the quality of the teachers in our schools. We need to encourage teachers to view themselves as expert and lifelong learners. Teachers need to change from being the fountain of knowledge to being facilitators of learning. We also need to change the role of the student from passive listener to active learner who is challenged to explore and construct personal explanations of the behavior of natural and technological systems. Teachers and students both have to realize that they are on a common path to lifelong learning.

There also should be mutual respect and collaboration among administrators, teachers, and students. Administrators must lead by example and become involved in the learning process as well. They need to view themselves as professionals whose main functions are to provide leadership and support for students and teachers.

Some of the features of supportive learning environments include cooperative learning, involving teachers and parents in school management decisions, and a shared philosophy of education.

Authentic Assessment Techniques

In this framework, the role of assessment is to provide feedback to the student, teacher, parents, and community that will allow them to determine how well the student is progressing toward achieving the standards. Assessment should be used as a means for helping students improve their understanding. We need to move away from total reliance on paper-and-pencil tests to the use of some long-term assessment techniques such as term projects and research papers that require students to demonstrate the application of concepts in solving problems. The key is to make sure that "design follows function." There must be high fidelity between assessment tools and standards.

Conclusion

Looking again at our diagram of the four cornerstones of the new educational system, it is important to understand two things: that the learner is at the heart of the system, and that the school is part of the larger community.

The child of today becomes the adult of tomorrow. Although we all know that, we should remind ourselves of it often. When we think of what we want the future to be for ourselves, our children, our country, and the world, we should realize that we can shape that future by the decisions we make today concerning how we educate our children.

Because schools are part of a larger community, they are affected by what happens in society—decisions that are made concerning policies and financial support are a reflection of how the community regards education. It is important that society recognizes and values what goes on in schools, not only for the contribution that students make to the community when they become productive and responsible members of a community, but also for the nurturing and enrichment of those intangibles that we value in our society.

CHAPTER II: MATHEMATICS, SCIENCE, AND TECHNOLOGY EDUCATION

To revise the process of education in New York State, the purpose of studying each discipline must be examined. The work of the Curriculum and Assessment Committee for Mathematics, Science, and Technology began with a discussion of the purposes and goals of the study of mathematics, science, and technology.

Educators are now answering the "Why study mathematics, science, and technology?" question differently than they did 30 years ago. In the past, only a small fraction of students studied these subjects. Today, it is popular consensus that mathematics, science, and technology are essential to the fundamental education of all students. All children should graduate from high school with, among other things, literacy in mathematics, science, and technology. But recent nationwide studies have revealed that America's students are significantly behind other nations in their comprehension of concepts of mathematics, science, and technology, and in skill application and problem solving. In the most recent international assessment of educational progress, American students ranked last in mathematics and ninth out of twelve jurisdictions in science. The reasons for studying these disciplines now and in the future have become more significant than in the past, both in New York State and in the nation.

Why Study Mathematics, Science, and Technology?

Mathematicians, scientists, and engineers are not the only citizens who require the skills, knowledge, and attitudes fostered by the study of mathematics, science, and technology. All young Americans should be equipped to work in, contribute to, benefit from, and enjoy our technological society. Integrating mathematics, science, and technology and/or connecting one to the other in a planned way with an emphasis on conceptual thinking and problem solving is essential to successful achievement of the standards delineated in this framework. Teaching and learning practices should be congruent with the desire to have citizens participate effectively in a society in which technology is an integral and significant force, both socially and in the workplace.

The committee concluded that the study of mathematics, science, and technology is critical, so that all students are able to:

- use various ways of asking questions, seeking answers, and designing solutions while applying a full spectrum of problem-solving strategies;
- think in terms of systems and learn to analyze problems holistically;
- process information by retrieving, analyzing, and synthesizing;

- use, apply, and make informed decisions on the products and processes of mathematics, science, and technology, for health, security, communication, transportation, environmental stewardship, work, and for pleasure and human development;

- be better prepared for jobs and careers, the vast majority of which will involve one or more of these disciplines.

Preparing students in these ways stimulate their interest in continuous learning in mathematics, science, and technology, can improve their achievement in these subjects, and can serve critical national and global needs. Students can choose to apply the skills and strategies of mathematics, science, and technology to various aspects of their lives.

General Principles for Learning in Mathematics, Science, and Technology

Basic principles provide the foundation for guiding the educational process for K-12 teaching and learning in mathematics, science, and technology.

Principle #1:
The learning process in grades K-12 must be integrated not only across areas of study within mathematics, science, and technology, but also across other academic disciplines.

Over the past fifty years, the formal education system, with few exceptions, has remained fragmented into subject-matter areas, and has been structured around specialized topics. This has typically led to disjointed collections of courses, with the interrelationship of subjects and topics either left to the student or assumed unnecessary. Effective learning requires that students learn concepts and adopt strategies that help them to see how the various parts of the world are related. The study of mathematics, science, and technology should be integrated to show interrelationships, and key concepts should be an integral part of other disciplines such as social studies, economics, and health. Students need to learn that seemingly unrelated events and observations can be understood by applying generic concepts that come from the "simultaneous" study of mathematics, science, and technology. (For example, rainbows, speech patterns, and musical notes are all complex waveforms that can be analyzed through and broken down into their basic sine wave building blocks.) Appropriate concepts should not be explored through separate courses alone but should be explored thematically in mathematics, science, and technology education, through team teaching, integrated coursework, or coursework within separate disciplines with planned connections made to each other.

Principle #2:
Mathematics, science, and technology need to be presented in a context appropriate to the student's level of understanding.

Learning becomes interesting, meaningful, and productive if students see connections between what they already know and what they are trying to learn. Mathematics, science, and technology, which often contain complex and abstract concepts, need to be taught within contextual frameworks that provide students with reference points to connect the new learning. Such a context not only provides the linkage with past learning but also provides new reference points for building upon.

Principle #3:
The curricula in mathematics, science, and technology should be designed to achieve certain fundamental standards for all students which, in aggregate, comprise literacy in these areas.

A number of constructive and timely studies and commissions have defined literacy in the subjects of mathematics, science, and technology. The studies listed below provide general guidelines for what needs to be learned in mathematics, science, and technology to constitute literacy and preparation for the "next steps" of job, community, or postsecondary educational participation. They are:

Curriculum and Evaluation Standards for School Mathematics, National Council of Teachers of Mathematics.

Science for All Americans, and *Benchmarks for Science Literacy,* **Project 2061**, a long-term initiative of the American Association for the Advancement of Science (AAAS).

What Work Requires of Schools, A SCANS Report for America 2000, The Secretary's Commission on Achieving Necessary Skills, U.S. Department of Labor.

A Conceptual Framework for Technology Education, International Technology Education Association (ITEA).

National Science Education Standards, A Working Paper on the National Committee on Science Education Standards and Assessment, National Research Council.

Principle #4:
Developing literacy in mathematics, science, and technology by all students is the highest priority. However, developing high levels of competency in mathematics, science, and technology is also necessary to stimulate and foster personal interests, civic responsibility, and career interests.

The primary goal of K-12 mathematics, science, and technology education should be a high level of literacy that will provide high school graduates with the tools for personal growth, entry into job markets, entrance into post-secondary educational institutions, and responsible citizenry. The educational system must also provide academic challenges to those students who show the inclination and capabilities to reach beyond basic literacy in mathematics, science, and technology. This will require enrichment courses and learning experiences that can become the stimuli for greater in-depth learning and specialized career preparation.

Principle #5:
The assessment of student progress and achievement must be tied directly to standards and support their attainment.

Assessment tools must be designed in such a manner that they not only measure progress but also reinforce the desired standards.

The Integration of Mathematics, Science, and Technology Learning

Real life takes place in a holistic context with all of us learning continuously through multidisciplinary experiences. Yet, in school, subject matter is typically presented in the context of specific disciplines. The historic separation of information into discrete streams of content blurs the natural relationships among things taught and learned for teachers and for their students. Schooling, to be most relevant to students, should instead mirror reality with students engaged in interdisciplinary activities anchored in real-world problems and environments.

Because of the special relationship that exists among mathematics, science, and technology, an integrated, interdisciplinary approach is especially appropriate. Knowledge and skills drawn from each combine in the visible evidence of the human-engineered world. Technological and mathematical tools contribute to our understanding of the natural world and provide the basis of contemporary science. Technology education can provide the focal point for active learning of mathematics and science as students design, build, and test devices; measure, monitor, and control processes; and build and use models and simulations.

In a sense, the heading of this section belies what this curriculum framework is about, for it is focused on the process of "reintegrating" mathematics, science, and technology, or rediscovering, uncovering, or restoring the natural linkages among these three disciplines. Of course, it is more than just these three ways of knowing; all ways of knowing are intricately linked in the human mind. The particularly close relationship among mathematics, science, and technology makes them an ideal place to begin reassociating knowledge.

Beyond the goal of helping children learn in a manner consistent with the context of the knowledge itself, there are a number of compelling reasons for integrating the results of learning.

- The results of learning that we seek for our students are to expand their confidence and ability in living, learning, working, enjoying, and problem solving in the real world. We cannot explain scientific inquiry well without also indicating how mathematical analysis and engineering design are so commonly used by scientists to expand the power of their inquiry. Similarly, today's engineer (and technological artist) needs principles and theories produced by scientific inquiry to help design and build optimum technological tools and techniques. Additionally, most mathematicians today use technological tools and the skills of systems analysis to address mathematical problems.

- Students learn best when instruction is provided in the context of problems and situations that are meaningful and of interest to them. Learning should also be related to the future adult roles that students will assume. One of these future adult roles is that of being technologically literate, which includes:
  —understanding modern technology—its capabilities and limitations, underlying related concepts, and societal impacts;
  —being able to apply scientific and mathematical principles which explicate devices and systems; and
  —evaluating the impact of progress on natural, human, and social systems.

- Scientific knowledge has grown exponentially, technology is advancing at an accelerated pace, and some fields of mathematics, such as logic and statistics, are increasingly relevant in dealing with the new knowledge and technology. Information science, which integrates mathematics, science, and technology, helps people deal with the information explosion.

- Identifying essential skills and understandings in mathematics, science, and technology is necessary in order to focus the efforts of educators and to avoid the encyclopedic approach to education, in which much is covered but little is learned. Leaders in mathematics, science, and technology education appear to have many goals in common, such as promoting problem solving, critical thinking, decision making, and action taking that provide a basis for identifying essential skills and understandings common to all three disciplines.

- The growth of mathematics, science, and technology in recent decades has had significant effects on human society and the living environment. An important goal of an integrated approach to mathematics, science, and technology education is to prepare students to assume a constructive role as mature citizens. Already many complex ethical issues have emerged as a result of the interactions among mathematics, science, technology, and society. For example, the widespread use of information systems raises questions of secrecy, privacy, and copyright. Furthermore, students need to understand how mathematics, science, and technology affect the environment and the potential for and limits to their roles in maintaining a healthy environment for future generations.

Students need to understand the nature of these disciplines, as well as their limitations. A major challenge for an integrated approach to mathematics, science, and technology education is to find educational strategies that help students learn how they can use mathematics, science, and technology to improve their lives, the lives of others in their family and community, and the lives of all those with whom they share the planet.

CHAPTER III: THE MATHEMATICS, SCIENCE, AND TECHNOLOGY STANDARDS

The Format of the Standards

Each of the nine standards is presented in a format that includes the statement of the content standard, a narrative overview describing the standard, a description of the major areas of study contained within the standard, a bulleted list of the key competencies and key concepts to be addressed, and performance standards with specific performance indicators for three levels—elementary, intermediate, and commencement.

The key concepts and key competencies are instructional strands that run through the three levels. The intent is to ensure continuity; that is, skills and content should be addressed continuously as students move from level to level.

The performance indicators focus on student progression from level to level, showing that students are progressively engaged in higher levels of complex thinking, a wider and deeper range of subject matter, and more independent learning. The key competencies and key concepts are explicated through the performance indicators at the three levels.

Mathematical Analysis is the first area of study addressed in Standard 1. The first key competency in the Mathematical Analysis section is "using abstraction and symbolic representation." At the elementary level, the first performance indicator relates to symbols. It states, "use special mathematical notation and symbolism to communicate in mathematics. Notation and symbolism help students to compare and describe quantities, express relationships, and relate mathematics to their immediate environments." Likewise, the first performance indicator at the intermediate and commencement levels also relates to the use of mathematical notation and symbols.

The second key competency in the Mathematical Analysis section of Standard 1 is "using deductive and inductive reasoning to reach mathematical conclusions." The second performance indicator at each level relates to the use of reasoning. Similarly, the third performance indicator at each level relates to the third key competency.

The diagram on page 21 shows the format of the Mathematical Analysis section of Standard 1. The format of the Scientific Inquiry and Engineering Design sections, which are the other areas of study addressed in Standard 1, is the same; the first key competency relates to the first performance indicator at each of the three levels, and so on.

Typically, class activities will engage the students in integrative experiences or tasks that allow them to demonstrate competence across a range of performance indicators. Such experiences may address multiple standards. Illustrative examples of such experiences are included in the standard section of the framework. As part of the framework development process, teachers are invited to share examples of classroom practice that relate to the mathematics, science, and technology standards.

The following are definitions of terms used in the diagram on page 21:

Standard—a statement of student learning that is composed of two parts: content standard and performance standard

Content Standard—knowledge, skills, and understandings that individuals can and do habitually demonstrate over time as a consequence of instruction and experience

Performance Standards—levels of student achievement in domains of study. Performance standards answer the question, "How good is good enough?"

Area of Study—a small number of related key concepts and competencies that form a set of powerful ideas. Together, areas of study constitute a discipline

Key Concepts—major ideas—what students should know

Key Competencies—important skills—what students should be able to do

Performance Indicator—description of what students should know and be able to do at various levels of schooling as they progress toward achieving the standards

Performance Task—what students might do to show that they have acquired the knowledge and skills described by the performance indicators. Performance tasks are intended to integrate performance indicators from a number of key concepts and competencies. These performance indicators might be drawn from within a standard, from across standards, and from across disciplines

Illustrative Examples of Performance Tasks—might be used to show student attainment of key concepts and competencies. Some are included at the end of Standard 1. Teachers and curriculum coordinators are encouraged to contribute examples of performance tasks for all the standards

SAMPLE FORMAT OF A STANDARD

STANDARD 1—ANALYSIS, INQUIRY, AND DESIGN

Content Standard Statement

Students will have knowledge, skills, and attitudes that empower them to use mathematical analysis, scientific inquiry, and engineering design, as appropriate, to pose questions, seek answers, and design solutions.

Description of the Content Standard

Overview

Mathematics, science, and technology are each distinguished by specific characteristics and processes which define the way mathematicians, scientists, and engineers approach their work. The student will be expected to . . .

Area of Study

Mathematical Analysis

Mathematical analysis is the process that uses the language and symbolism of mathematics to represent abstractions, manipulate numbers, construct mathematical models for both practical and theoretical situations, . . .

Key Concepts and Competencies related to Area of Study

The key concepts and competencies related to mathematical analysis are:

- using abstraction and symbolic representation
- using deductive and inductive reasoning to reach mathematical conclusions
- using critical thinking skills in the solution of problems

Symbols are used to represent abstractions that enable an individual to proceed with reflective thoughts about the abstractions, relating them to various concrete objects and other abstractions. The association of symbols with abstractions is essential for communication with others about the abstraction. Symbols become objects that can be used in a variety of mathematical activities.

Reasoning and critical thinking should be encouraged so that students can analyze mathematical situations and draw logical conclusions. Students should be able to analyze and make sense of mathematical situations. In the past, students have often memorized mathematics without having had any idea of its meaning. Critical thinking will enable students to formulate mathematical ideas through both inductive and deductive means.

Problem solving involves much more than getting an answer to a mathematical situation. The emphasis in problem-solving instruction should be on developing strategies for the solution of problems rather than on simply finding the answer to a "simple" word problem. Problems should be open ended, often with multiple answers, allowing students to use a variety of techniques to arrive at a solution. Problem-solving skills developed by students should provide them with techniques to solve new and unfamiliar problems.

Performance Standards

Performance Indicators related to Key Concepts and Competencies

At the elementary level, students	At the intermediate level, students	At the commencement level, students
use special mathematical notation and symbolism to communicate in mathematics. Notation and symbolism help students to compare and describe quantities, express relationships, and relate mathematics to their immediate environments	extend mathematical notation and symbolism to include variables and algebraic expressions in order to describe and compare quantities and express mathematical relationships	use algebraic and geometric representations to describe and compare data. Mathematical investigations can be made to assist students in formulating mathematical generalizations
use simple logical reasoning to develop conclusions, recognizing that patterns and relationships present in the students' environment assist them in reaching these conclusions	use deductive reasoning to construct, evaluate, and validate conjectures and arguments, recognizing that patterns and relationships can assist in explaining and extending mathematical phenomena	use deductive reasoning to construct, and evaluate conjectures and arguments, recognizing that patterns and relationships in mathematics assist them in arriving at these conjectures and arguments
explore and solve problems generated from school, home, and community situations. When possible, students should model the problems, using concrete objects or manipulative materials	apply mathematical knowledge to solve real world problems and problems that arise from the investigation of mathematical ideas. Students should model these problems, using representations such as pictures, charts, and tables	apply algebraic and geometric concepts and skills to the solution of problems. The language of algebra and geometry provides a new dimension for the modeling of problems. Strategies already learned may be applied to new or novel situations

Illustrative Examples of Performance Tasks

Illustrative examples of performance tasks are included at the end of Standard 1. Teachers and curriculum coordinators are encouraged to contribute examples of performance tasks for all the standards.

Students will have knowledge, skills, and attitudes that empower them to use mathematical analysis, scientific inquiry, and engineering design, as appropriate, to pose questions, seek answers, and design solutions.

We invite comment on all the standards.

Overview

Mathematics, science, and technology are each distinguished by specific characteristics and processes that define the way mathematicians, scientists, and engineers approach their work. Students will be expected to understand the crucial dimensions that distinguish essential processes in mathematics, science, and technology and the scope and limits of these ways of knowing and doing; to know when these modes of inquiry and their tools are appropriate and when they are not; and to be able to apply these processes when seeking solutions to problems.

Mathematical Analysis

Mathematical analysis is the process that uses the language and symbolism of mathematics to represent abstractions, manipulate numbers, construct mathematical models for both practical and theoretical situations, reach conclusions, and solve problems. As a theoretical discipline, mathematics may be considered as a science of patterns and relationships. Mathematical analysis, therefore, explores the possible relationships among abstractions whether or not these abstractions have counterparts in the real world. These abstractions include such ideas as numbers, geometric figures, and sets of equations. As students study these patterns and relationships they should be presented with situations requiring mathematical reasoning and decision making. By the time students reach the commencement level, they should have a good understanding of mathematics as a system and of the structure of mathematics. A mathematical system consists of undefined and defined terms, operations, postulates, and theorems and is based on deductive logic. Students should investigate number systems, algebraic systems, and geometric systems.

*The key concepts and competencies related to mathematical analysis are:

- Using abstraction and symbolic representation
- Using deductive and inductive reasoning to reach mathematical conclusions
- Using critical thinking skills in the solution of problems

Symbols are used to represent abstractions that enable an individual to proceed with reflective thoughts about the abstractions, relating them to various concrete objects and other abstractions. The association of symbols with abstractions is essential for communication with others about the abstraction. Symbols become objects that can be used in a variety of mathematical activities.

*See sidebar on page 27.

Reasoning and critical thinking should be encouraged so that students can analyze mathematical situations and draw logical conclusions. Students should be able to analyze and make sense of mathematical situations. In the past, students have often memorized mathematics without having had any idea of its meaning. Critical thinking will enable students to formulate mathematical ideas through both inductive and deductive means.

Problem solving involves much more than getting an answer to a mathematical situation. The emphasis in problem-solving instruction should be on developing strategies for the solution of problems rather than on simply finding the answer to a "simple" word problem. Problems should be open ended, often with multiple answers, allowing students to use a variety of techniques to arrive at a solution. Problem-solving skills developed by students should provide them with techniques to solve new and unfamiliar problems.

At the elementary level, students

use special mathematical notation and symbolism to communicate in mathematics. Notation and symbolism help students to compare and describe quantities, express relationships, and relate mathematics to their immediate environments

use simple logical reasoning to develop conclusions, recognizing that patterns and relationships present in the students' environment assist them in reaching these conclusions

explore and solve problems generated from school, home, and community situations. When possible, students should model the problems, using concrete objects or manipulative materials

At the intermediate level, students

extend mathematical notation and symbolism to include variables and algebraic expressions in order to describe and compare quantities and express mathematical relationships

use inductive reasoning to construct, evaluate, and validate conjectures and arguments, recognizing that patterns and relationships can assist in explaining and extending mathematical phenomena

apply mathematical knowledge to solve real-world problems and problems that arise from the investigation of mathematical ideas. Students should model these problems, using representations such as pictures, charts, and tables

At the commencement level, students

use algebraic and geometric representations to describe and compare data. Mathematical investigations can be made to assist students in formulating mathematical generalizations

use deductive reasoning to construct, and evaluate conjectures and arguments, recognizing that patterns and relationships in mathematics assist them in arriving at these conjectures and arguments

apply algebraic and geometric concepts and skills to the solution of problems. The language of algebra and geometry provides a new dimension for the modeling of problems. Strategies already learned may be applied to new or novel situations

Scientific Inquiry

Scientific inquiry can best be understood by looking at what various kinds of scientists actually do. In particular, scientists observe the natural world and build explanatory structures, telling stories which can be tested to determine whether they match the natural world. Approaching the study of science in school in a questioning mode is in harmony with the practice of science, as compared with presenting science by talking about it. There is no one set of steps that scientists always follow; many paths lead to the development of scientific evidence. Observation, experimentation, analysis, synthesis, and validation are elements of most scientific inquiry that can be used by anyone to gain new information and understandings. When students engage in inquiry, they use both practical, hands-on skills and thinking skills. The principles of logical reasoning are important in that scientific arguments are expected to conform to criteria of inference, demonstration, and common sense, as logical reasoning connects evidence and assumptions with conclusions. The validity of scientific claims is ultimately settled by referring to observations of phenomena. In situations that range from natural settings to contrived laboratory situations, investigators make observations and measurements as they seek accurate data. As inquiry proceeds, findings are developed and communicated to others. The findings become accepted as scientific evidence when tested by independent investigators and when replication verifies the findings. Scientific inquiry can result in information that when connected to previously known information generates powerful predictions, hypotheses, theories, and laws. Inquiry in the classroom can and should engage students in a series of creative, iterative, and systematic procedures.

*The key concepts and competencies related to scientific inquiry are:

- Generating explanations of natural phenomena
- Testing ideas through empirical work
- Honing ideas through reasoning, discussion, and research

At the elementary level, students

form testable ideas based on everyday experience and/or on some prior knowledge and understanding. Often, it is useful for the student to pose the idea in the form of a usable question to address, such as "How can an object which sinks be made to float by itself?"; examine tested ideas in light of the interpretations made, drawing conclusions and/or making further predictions; generate explanations of how and why objects appear and behave as they do

At the intermediate level, students

generate testable ideas and formulate hypotheses involving causal links and qualitative, and/or quantitative relationships among a number of variables, based on personal and/or scientific knowledge or theories. For instance, students can develop a plan to determine whether the average amount of residential solid waste (2.7 kg) claimed to be thrown out each day by every person in New York State is a personally accurate average; evaluate hypotheses in light of the drawn inferences, modifying personal and/or scientific explanations where necessary

At the commencement level, students

develop testable ideas, formulate hypotheses, and logically sequence a set of hypotheses that can be tested qualitatively and/or quantitatively to answer questions, assess predictions, and/or extend knowledge based on an existing scientific principle or theory; formulate usable questions, and after conducting systematic observations, interpret and analyze data, draw conclusions, validate and communicate results, and formulate new predictions or revised hypotheses

*See sidebar on page 27.

At the elementary level, students	At the intermediate level, students	At the commencement level, students
make observations of objects and events, using the senses and instruments that extend the senses; select and use standard measuring devices to collect data on such physical quantities as length, mass, volume, temperature, and time; organize observations of objects and events, recording measurements through classification and the preparation of simple charts and tables; interpret from organized observations and measurements simple patterns, sequences, or relationships among variables	use instruments to extend the senses when observing and documenting phenomena; select measuring devices and units that are appropriate for the degree of accuracy necessary to investigate the variables; design charts and tables, preparing graphs to display data; interpret charts, tables, and graphs to determine directly proportional, inversely proportional, or null relationships among variables	coordinate and implement an experiment, distinguishing between pertinent and extraneous observations and between observations and inferences, identifying sources of error in making observations; evaluate the nature of scientific evidence and know the scope and limits of scientific inquiry; choose and use specialized devices to measure quantities that depend on more than one variable, while recognizing the limitations of use and precision of such devices; develop and interpret tables, charts, and matrices to organize and relate data and employ graphing systems; assess the degree of correspondence and discrepancies between a set of hypotheses and the inferences drawn from actual results
hone ideas through reasoning and discussion with others and through research techniques such as interviewing experts. Since students vary considerably in their experiences, it is useful to use instructional techniques such as cooperative learning and library research to help students hone ideas	hone ideas through feedback obtained from formal oral proposals and group discussion, and through investigations which include information retrieval, preparation of oral reviews of the literature, and defense of ideas. For instance, students can work together to design the simulated siting of a highway based upon information they obtain on the local social, technological, and geological setting, changing their group proposal of that design as they obtain additional information from a variety of sources	hone ideas through a public forum in which ideas are presented and defended in discussion and revised if necessary, and through use of a variety of resources including a review of the literature, develop a written report that features an assessment of the merits of the ideas and rebuttal or acknowledgment of criticism of them by peers and others. For instance, students can plan and carry out an investigation of selected properties of water compared to the properties of another common substance such as corn oil, with findings shared at a simulated scientific conference and leading to another round of laboratory research

Engineering Design

Engineering design is a planned process of making design choices and tradeoffs within given constraints, which leads to the development of a product or system that satisfies human needs or wants. It is a multidisciplinary problem-solving process which involves the synthesis of technical, scientific, mathematical, societal, ethical, environmental, aesthetic, and linguistic knowledge and skills. The engineering design experience is a valuable integrating endeavor for students.

Engineering Design Problems

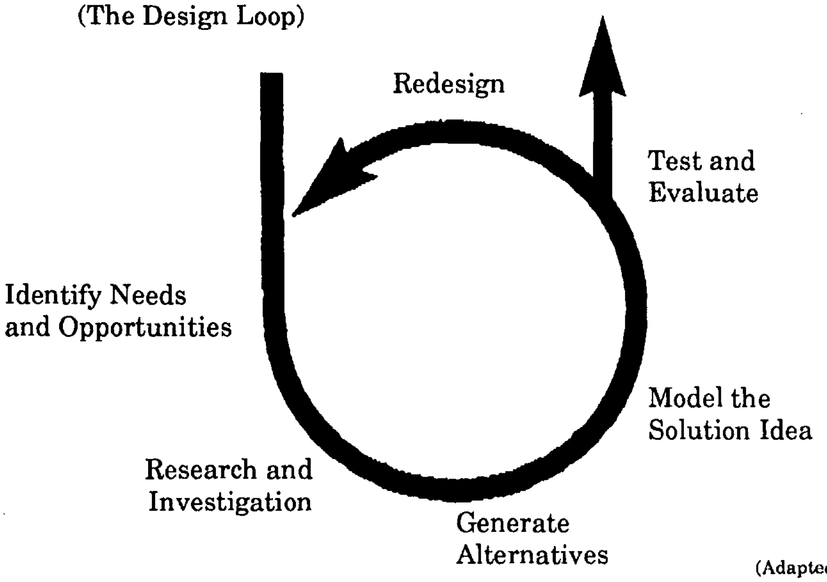
In standard school subjects and textbooks, problems are usually well defined; that is, given this—find that, and students are accustomed to narrowly focused problems. A typical textbook problem of that type is: If a train leaves the station at noon and arrives at a town 200 km away by 4 p.m., at what average speed must it travel?

Engineering design problems are seldom as well-defined, when first encountered. For example, if the problem involves the design of a home, before the design solution can be realized, many choices, decisions, and tradeoffs have to be made relative to such things as heating and insulation costs, shapes and sizes of rooms, placement of the house on the lot, and how features of the house relate to its cost. The architect, the contractor, and the customer must meet to clarify the problem statement and discuss solutions. Knowledge drawn from several fields must be integrated into the design solution. An understanding of climate control within the home, building construction, cost analysis, legal procedures, and interior design all shape the design of the home. The design process begins with broad ideas and concepts and continues in the direction of ever increasing detail, resulting in an acceptable solution.

The Process of Engineering Design

Engineering design is an iterative process; some decisions are made without complete knowledge and must be revisited. To help students better understand engineering design, one method is shown which includes several phases. In this model, the phases are often referred to as the Design Loop to indicate the ongoing, iterative nature of the process. The Design Loop involves a number of repeatable steps that engage students in the design process in a manner similar to adult professionals who do engineering design. Engineers and other designers do not always follow these steps in a sequence. Often, people move back and forth from one phase to another as needed. However, for purposes of instruction it may be useful to point out to students how the following phases are components of the engineering design process.

The Engineering Design Process
(The Design Loop)



(Adapted from)

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Although the processes of mathematical analysis, scientific inquiry, and engineering design each reflect unique combinations of knowledge and skills, there are elements embedded within the processes that are particularly powerful because they are transferable to many other areas of study. These include generating explanations, honing ideas, communication, logic and reasoning, measuring, modeling, and research and investigation.

*The key concepts and competencies related to engineering design are:

- Identifying needs and opportunities—investigating the problems and the possibilities; specifying design criteria
- Researching and investigating—gathering information, searching for solutions, reviewing prior attempts to solve similar problems
- Generating alternatives—developing alternative designs, analyzing what works and what doesn't; examining tradeoffs
- Modeling the solution—developing the prototype
- Testing and evaluating—testing the result, and assessing the process and impacts

* See sidebar.

Progression in Engineering Design Instruction

Engineering design exists on a continuum. Children at the early level of schooling can design solutions to technological problems. Design-and-construct projects should be a central student activity and involve the use of hand tools and common materials (e.g., wood, plastic, fabric). The problems will most likely come from familiar contexts and involve the child's world of imagination. For example, 5-year-olds can be asked to bring their teddy bears to school and design comfortable beds for them to sleep in until the next morning. Age-appropriate mathematics and science concepts can be applied to the design solution even in the early school years. The bed will be one teddy long, and one teddy wide and will have to be made from materials that are soft and comfortable. A wide variety of design solutions will emerge as students employ different materials in the construction of the solution. Older elementary school children might be challenged to design a device to perform only a simple function, such as hoisting a weight or turning a corner. The built devices can be evaluated by staging a contest, with points awarded for the quality of a device's performance.

As students progress to later elementary and middle levels, design problems can come from areas of more general interest and involve more collaborative work and communication among members of design teams. Design problems might still be narrowly constrained. For example: given a collection of resources, design a wheeled toy for a young child involving the use of linkages and cams or cranks to make parts move on the toy. Age-appropriate mathematics and science concepts should be identified whenever possible. For example when mechanical movements are used, levers, gears, cams, and linkages should be explained. Children might become involved in the design and making of an innovative range of soft-centered chocolates, using enzymes to ensure that the centers remain soft. The activity might include marketing, mold design, packaging, and final sale. Charts and graphs could be used to display costs and customer satisfaction data. At the middle level, teachers might still provide substantial support to students as they work through the solution process by breaking the problem into understandable and achievable parts, and by providing individual and group instruction relative to the safe and proper use of tools, materials, and technical processes.

Design solutions proposed by commencement level students should reflect their knowledge of principles of design (e.g., balance, symmetry, form) and the recognition that engineering exists within human and environmental contexts. Economic constraints, environmental demands, social impacts, and quality and reliability issues can be taken into account by older students who will be addressing engineering design problems that are more complex and more rooted in the real world. At this level, technical design solutions should represent more divergent thinking and sophisticated processes of analysis. Design solutions should be well matched to the human user. Human factors should be considered in the design of a product. These ergonomic considerations deal with the interaction of humans with machines and result in designs that provide ease of use, comfort, and safety. Additionally, designs should reflect the need to protect the environment. Factors such as disposability and recyclability should be part of the design criteria.

In developing alternative solutions, mathematical modeling and systems analysis are important tools that will play an expanding role in the conception and planning of engineering solutions. Mathematics and science should increasingly be used as predictive and analytic design tools at this level.

Group dynamics and collaborative problem solving will play more central roles at the high school level. As members of design teams, students should be willing to challenge their own ideas and to integrate their ideas with those of others. They should understand the social dynamics of their work and communicate their understandings in ways that are clear and persuasive.

At the elementary level, students	At the intermediate level, students	At the commencement level, students
express in drawings or words examples from the personal or family environment or the world of imagination, material objects that might be modeled or made differently, and suggest ways in which something can be changed, fixed, or improved	identify needs and opportunities for technical solutions from an investigation of situations of general or social interest; present findings to the class, using oral, visual, and written means and annotated drawing techniques	initiate and carry out a thorough investigation of an unfamiliar situation; identify needs and opportunities for solution by technological means, choosing from a wide range of analytic tools; present a clear description of conclusions to an interested and literate audience, using appropriate communication techniques
investigate ideas from books and magazines; interview family, friends, neighbors, and community members; discuss and document through notes and sketches how findings relate to the problem	locate and utilize library resources; interview and survey interested parties and subject specialists to clarify a problem	identify, locate, use, and evaluate a wide range of information resources including books, magazines, videotapes and films, and electronic databases, and solicit expert opinions through written and oral means to clarify a problem and its constraints, and suggest solutions
generate several ideas for possible solutions, individually, and through group activity; evaluate the ideas and determine the best solution; explain reasons for the choices	with imagination and flexibility generate several ideas for alternative solutions, using group and individual ideation techniques (group discussion, brainstorming, forced connections, role play); defer judgment until a number of ideas have been generated; evaluate (critique) ideas, discuss tradeoffs, and express and defend opinions	generate a number of creative solution ideas, and break ideas into the significant functional elements; thoroughly explore a variety of possible refinements; use brainstorming, graphic ideation, and other techniques; choose the optimal solution to the problem, clearly documenting ideas against design criteria and constraints; justify the choice, using a full range of communication techniques; explain how human values, ergonomics, and environmental considerations have influenced the solution
under supervision, plan and safely build a model of the solution; embellish the model, creatively using familiar materials, processes, and hand tools	develop plans, including measurements and details of construction; accurately construct a model of the solution, exhibiting a degree of craftsmanship; demonstrate safe and efficient use of a variety of tools, machines, materials, and technical processes	using a variety of verbal, numerical and graphic planning strategies, develop work schedules and working plans which include optimal use and cost of materials, processes, time, and expertise; interpret plans to accurately construct a model of the solution, incorporating developmental modifications while working to a high degree of quality (craftsmanship); choose and demonstrate creative, safe and skillful use of a wide range of tools, materials, and technical processes
discuss how to best test the solution, perform the test under teacher supervision; record and portray results through numerical and graphic means; discuss orally why things worked or didn't work; summarize results in writing, suggesting ways to make the solution better	in a group setting, relate design specifications to the development of an appropriate test of success, and perform that test; record, present, and evaluate results, using simple means of quantifying and interpreting; consider and describe how the solution might have been modified for different or better results; explain why there is no perfect design and what tradeoffs were made	in a group setting, design a test of the solution to the problem, considering both specific problem criteria and general design criteria, and perform the test; record, portray, and logically evaluate performance test results through quantitative, graphic, and verbal means; effectively and persuasively use a variety of creative verbal and graphic techniques to present conclusions, predict impacts and new problems, and suggest and pursue modifications

Illustrative examples of Intermediate Level Performance Tasks for Standard 1

We encourage teachers to submit similar tasks for each standard that they have used successfully with their students.

Mathematical Analysis

Performance Indicators: Students apply mathematical knowledge to solve real-world problems that arise from the investigation of mathematical ideas. Students should model these problems, using representations such as pictures, charts, and tables.

Performance Task: You have 24 meters of fencing to make a barnyard which is to be rectangular in shape. You want to use the barn as one side of the yard. What should the dimensions of the yard be in order to maximize the area? Draw a graph of the data to help you get an answer to the problem.

Scientific Inquiry

Performance Indicators: Students suggest testable ideas and formulate hypotheses involving causal links and qualitative and/or quantitative relationships among a number of variables, based on personal and/or scientific knowledge or theories.

Performance Task: You and two other students are to design a classification scheme. The scheme will be based on physical characteristics that will allow you to separate chips of plastic, whether or not they happen to be marked with a recycling (resin) code. The teacher will give you a bag in which you will find a coded piece of plastic and several uncoded pieces. Use the following physical tests, as well as others that you develop yourselves, to figure out which of the chips in the bag are made from the same kind of plastic as the coded chip.

How do particular chips appear to you? (clear, shiny, dull, etc.)

How do particular chips react when they are bent?

Which chips float in a sugar-and-water solution?

Which chips float in an alcohol-and-water solution?

Make a table to record your results, and present your findings to the class. Based on your findings and those of the other groups (for differently coded plastic chips), design a classification scheme for identifying uncoded chips of plastic.

Engineering Design

Performance Indicators: Students identify needs and opportunities for technical solutions; generate several ideas for alternative solutions; evaluate ideas; construct the solution; evaluate results

Performance Task: Your school is planning a weekend camping trip that includes an all-day hike. You and your friends have identified a need to plan a lunchtime meal that can be easily carried in a backpack.

Design and make a food product for lunch that will provide one-third of the daily nutritional requirements for 13/14-year-old students. The product should maintain its shape and texture within a temperature range of 40-70 degrees F. You may wish to use items such as the following: dry ingredients (e.g., flours, sugars, dried fruit, nuts); perishable ingredients (e.g., fats, eggs, milk, cheese); fruits and vegetables (e.g., bananas, oranges, carrots, potatoes).

Test market your food product with your schoolmates and present your results to the class, using drawings, charts, photographs, and actual samples of the product.

Students will acquire an understanding of the basic concepts of systems and their uses in the analysis and interpretation of interrelated phenomena in the real world, within the context of mathematics, science, and technology.

Overview

A system is a union of diverse parts subject to a common plan or serving a common purpose. Through the framework of systems thinking, students will see interrelationships as well as objects, patterns of change, and static snapshots. They will have the ability to use selected tools of systems dynamics to deal with whole systems, interdependencies, and dynamics, and they will be able to transfer knowledge from the familiar to the unfamiliar.

Students will study, operate, and construct individual representative systems and understand the commonalities that exist among all systems (generic systems model). They will use computer-based systems to model and simulate natural and human-made phenomena; to measure and control objects, processes, and systems; and to improve decision making.

A system is described by the boundaries and resolution of detail imposed. The system we choose to examine could be as broad as the entire universe or as specific as the energies and interactions of the fundamental particles of nature.

When a need has been identified, the system to be observed is arbitrarily defined and analyzed with respect to boundaries and detail.

Systems can be categorized in various ways. For example, they can be defined as natural and constructed systems relating to the structures and interrelationships found in the natural world or to the structures and interrelationships created through human endeavor.

Systems are also expressed in terms of their scale. They can be viewed macroscopically (as galactic or solar systems, global communications and transportation networks, or animal and plant populations), or microscopically (as molecular or atomic systems, integrated circuits, transistors, or cells).

Many technological systems are controlled automatically by feedback. Feedback is derived from monitoring the output of a system and comparing the output (actual results) to the input (desired results). These systems are called closed-loop systems because the feedback "closes the loop" from output to input. Closed-loop systems adjust themselves if the conditions around them change. Thermostatically controlled heating systems and homeostatic systems in living organisms are examples of feedback control systems.

Some systems are operated without feedback. These are open-loop systems. A washing machine controlled by a timer and a gas stove are examples of open-loop systems. If conditions change (for example, if the water gets hotter or the flame is reduced), the output of these systems will change. There is no feedback to adjust for changing conditions.

Engineered Systems

Engineered systems are technological systems that people have designed to achieve a desired result. Engineered systems produce outputs such as products, services, other systems, or environments. In engineered systems, the system boundaries will be determined by whether we take a macroscopic or microscopic view. A communication system can be as large as the global telephone network or as small as the local area network or a digital telephone switch. When analyzing system interactions and determining how outputs from one system become inputs to another, system boundaries must be carefully defined.

Because human endeavor exists in the context of the larger environment, technological, natural, and social systems interact. Virtually all technological systems have some impact on the natural world and on humans. We design technological systems to try to change the world to suit us better. The results of changing the world, however, are often complicated and unpredictable.

In addition to desired and expected outputs, technological systems can also produce undesired and unexpected outputs, such as pollution and crowded highways. Thus, there are many interactions between technological systems and natural systems. Optimal system design involves anticipating undesired outputs and limiting them to acceptable levels. Often, constraints such as economic cost and time considerations require engineers to make tradeoffs which lead to acceptance of some undesired system outputs.

System inputs are of two types. The command input is the desired result that a system is designed to achieve. The command input can be the desired volume of a receiver, defined by the setting of an electronic volume control, or the desired temperature in a room, defined by the setting of a thermostat. The desired result is achieved by combining resource inputs, such as energy, materials, and information, in an ordered and specified manner (system process). The system output is the actual result.

The output is not always what is desired, and therefore is often monitored (through feedback) and compared to the desired result. Control systems (those employing feedback mechanisms) adjust in response to the feedback, so that the actual result more closely approaches the desired result.

The key concepts and competencies related to engineered systems are:

- Identifying boundaries
- Working with inputs and outputs
- Identifying interactions among the elements of systems
- Working with feedback and control

At the elementary level, students	At the intermediate level, students	At the commencement level, students
explain how technological systems are used to satisfy human needs and wants; identify and describe familiar technological systems; assemble and operate simple technological systems (e.g., doorbell, battery, and switch; mechanical toys; Lego, Capsela, or Erector set systems) and identify the component subsystems	explain how the output from one subsystem might provide the input to another subsystem within a larger system (e.g., the driver steps on the accelerator, a mechanical linkage causes fuel to flow, the fuel causes combustion within the cylinder)	explain how systems are not mutually exclusive and that systems may be so closely related that there is no way to draw boundaries that separate all parts of one from all parts of the other (e.g., the communication system, the transportation system, and the social system are extensively interrelated; one component, such as an airline pilot, can be a part of all three)
identify the outputs resulting from familiar systems at home, school, or in the community (e.g., hot air from hair driers, music from stereo systems); describe resource inputs such as energy sources, information, and materials that are processed by these systems	assemble, operate, and explain the operation of technological systems which produce outputs including products, energy, and information. Explain how desirable, undesirable, expected, and unexpected outputs might be observed during the processing of materials, energy, and information; analyze the processes, identify the resource inputs, and recommend ways to avoid undesirable outputs	identify desirable, undesirable, expected, and unexpected outputs resulting from a technological system employed at a regional or local level; research, analyze, and make recommendations to improve the system, considering the mix of resource inputs, and economic, social, political, and environmental impacts
identify some desirable and undesirable outputs from technological systems (e.g., noise from the refrigerator, draft from the heater, television commercials that are louder than the normal programs); use technology to enhance a natural system (e.g., the growing of fish, plants, insects)	describe how new technologies have evolved as a result of combining existing technologies (e.g., photography evolved from combining optics and chemistry; the airplane evolved from combining kite and glider technology with a lightweight gasoline engine); design and model a technological system that can monitor some aspect(s) of a natural system (e.g., temperature, wind speed, rain, noise) and give notice if certain limits are exceeded	provide examples and explain how modern high technologies involve the confluence of numerous science-based technological systems; design and model a technological system to address a societal or environmental issue (e.g., waste disposal, mass transit, water quality)
use a software program (such as LOGO) at an appropriate level to write a sequence of instructions to control the motion of a computer-driven open-loop system; using teacher provided materials, assemble and operate a simple system including a feedback loop (e.g., photocell and relay, float mechanism)	use a software program at an appropriate level to write a sequence of instructions to control the motion of a computer-driven closed-loop system; employ electrical, mechanical, electromechanical, pneumatic, and hydraulic controllers (e.g., high and low current switches, relays, solenoids, valves, pistons) to control a variety of systems; identify, describe, and use a variety of sensors (pressure sensors, photocells, meters, float mechanisms, etc.) to monitor system outputs	design and construct a computer-controlled closed-loop technological system, using electronic sensors for feedback control; design, assemble, operate, and test a feedback control system to produce products, energy, or information; define its components, identifying command and resource inputs, the process(es), the outputs, and the monitoring and control functions

Natural Systems

Natural systems involve component parts or subsystems, interactions among subsystems, inputs and outputs, and feedback and control mechanisms. Natural phenomena that have some influence on one another and constitute a unified whole can be viewed as a system having defined boundaries. Drawing systems boundaries helps the investigator to understand what is going on. For instance, the conservation of mass during burning was not recognized until the gases produced were included in the system whose weight was measured. Also, people believed that maggots derived spontaneously from garbage until experimental evidence was obtained that egg-laying flies were the preexisting life form that, following mating, produced the next generation of maggots. When defining natural systems such as ecosystems or the solar system or a weather system, enough parts need to be included so that the relationship of one part to another makes sense. What makes sense depends on what is perceived as the purpose of the system. For example, if the focus is the energy flow in a forest ecosystem, solar input and the decomposition of dead organisms should be included, whereas if the focus is predator/prey relationships, those parts could be ignored. Having defined boundaries permits careful consideration of what influences a system and how a system behaves. This is accomplished by considering a system's inputs and outputs. For example, in a natural community the output of one part of a system can be the input for another; the fruit/seeds and oxygen that are outputs of plants might be inputs for other organisms in the system; or the carbon dioxide and fecal droppings that are the outputs of animals may serve as inputs for the plants. When some portion of the output of a system is included in the system's own input, such feedback serves as a control on what goes on in a system. Feedback can encourage more of what is happening, discourage it, or modify it. For example, if the deer population in a particular location increases in one year, the greater demand on the scarce winter food supply may result in an increased starvation rate the following year, thus reducing the deer population.

The key concepts and competencies related to natural systems are:

- Identifying boundaries
- Working with inputs and outputs
- Identifying interactions among the elements of a system
- Working with feedback and control

At the elementary level, students	**At the intermediate level, students**	**At the commencement level, students**
identify common natural phenomena that can be considered to be systems, such as a human being, a plant population in a field, soil, the Earth, substances, or energy and matter interactions	understand that natural systems are created and defined by people, as they compare systems having sufficiently broad boundaries to enhance understanding. For example, organs, the solar system, the 100+ elements, or the Earth's moving crust have effectively defined boundaries compared to the more limited boundaries that have been conceived for some systems and have historically led to misunderstandings (e.g., tissues, stationary Earth, the four Greek elements, a single earthquake)	explain and provides examples to show that scientists draw boundaries around natural systems. Sometimes the space boundaries are large (e.g., the universe, the Earth, a biome), and sometimes the boundaries are small (e.g., a chemical reaction, a molecule, an atom). They are drawn according to the experimental and explanatory intentions.
identify types of substances and forms of energy that enter or leave natural systems, such as food, water, and air that enter human beings and wastes that leave; rain water and dead leaves that enter soil and minerals and small animals that may leave; or light that both enters and leaves the Earth	use flow charts and diagrams to show that output from one part of a system (e.g., oxygen, sugar, energy from plants in a forest; heat contained in water vapor in Earth's atmosphere) can transfer material, energy, or information as input to other parts of the system (e.g., animals in a forest, the Earth's oceans and continents)	in an investigation of a complex physical or living system (e.g., chemical synthesis reaction, photosynthesis in plants, respiration in insects, biological rhythms in vertebrates) vary the input and monitor the effects of such changes upon the output, summarizing such relationships in a prepared report

At the elementary level, students	At the intermediate level, students	At the commencement level, students
identify interactions among system components: an example from the physical setting is a weather system wherein warm air cools as it rises, with clouds forming when the dew point is reached; an example from the living environment is the predator-prey relationships that exist in a natural community; and an example from the human organism is increased blood flow as indicated by pulse rate in response to increased rate of movement of the large muscles of the body	identify interactions among system components: examples include being able to relate movements of tectonic plates to long-term changes in the features of the Earth's surface; being able to predict the effect of a change in quantity or quality of a component of an ecosystem; and being able to recognize those actions that promote health for individuals	identify interactions among components of a system: examples include being able to predict changes in pressure, volume, and temperature of a gas, given a situation in which one of the components changes in a particular way; being able to identify the particular biome being described when climate, temperature, and rainfall data are given; and being able to relate in detail how the tissues of a given organ work together, carrying out the function of that organ
provide examples to illustrate that natural systems have ways to control themselves when conditions change: for example, the process of perspiration leads to a cooling of the human body; winds, rain, and ocean currents spread heat all over the Earth; water and ice wear down mountains at all stages of their existence	describe simple feedback mechanisms for natural systems that encourage (or discourage) what is going on: an example of encouragement is better adapted members of a species showing higher survival and/or reproductive success; an example of discouragement is an increase in the size of an animal population resulting in greater starvation and predation for the population; another example of discouragement, which illustrates reduction of discrepancies from some optimal value, is the thermoregulation that takes place in birds and mammals	explain how multiple feedback mechanisms in a complex physical or living system such as the water cycle, plate tectonics, a human organism, or an ecosystem help maintain the overall stability of the system by channeling some of the system's output to serve as input in the form of materials, energy, and/or information

Systems Modeling

Systems modeling is a powerful conceptual tool for analyzing, correcting, or developing a system. A model of a system is created to permit observation and testing of the system's behavior during normal or stressed operation. Modeling can be safer and less expensive, in terms of time and other resources, than the actual construction.

Modeling involves the use of various techniques for studying the behavior of systems. Broadly speaking, these techniques can be categorized into two types: descriptive modeling and functional modeling.

Descriptive models include pictorial models such as block diagrams, flow charts, and graphs. One such model is the universal systems model which views a system in terms of its input, process, output, feedback, and control elements. All systems, whether economic, social, political, natural, or technological, can be thought of as comprising these generic elements. Thus, systems modeling in which the universal systems model is used can help people transfer knowledge from one system to another. They are able to see familiar patterns reoccurring, although a particular system may be new to them.

Functional models are used to study how a system might behave under changing conditions. These models include physical models (or replicas of real systems with moving parts), and computer simulations that support "what-if" investigations of system behavior.

The key concepts and competencies related to systems modeling are:

- Functional modeling
- Descriptive modeling

At the elementary level, students	At the intermediate level, students	At the commencement level, students
use simple open-loop systems (e.g., shaving foam from a spray can, bubble gum machine, mechanical toys); use modeling hardware (e.g., Lego, Fishertecnik, Capsela, etc.) to assemble and operate a simple system; use a computer simulation to observe and participate in a controlled experience, which includes decision-making points, with the possibility of multiple resultss	write a simple control program and implement a computer-controlled system using modeling hardware and a computer interface; use a software simulation to control a complex, costly, and/or dangerous activity, such as driving, flying, or operating a machine; describe how modeling and simulations can save resources (e.g., time, money, and human life); use basic level CAD modeling software to design a product or structure	use modeling hardware to design and build a complex computer-controlled functional model of a technological system, involving sensing and control subsystems, and computer programming; select and use application-specific modeling and simulation software to design, implement and test technological, mathematical and scientific systems
draw a pictorial diagram explaining a system's operation; compose a written description of how simple open- and closed-loop systems work, including labeled diagrams; explain the purpose of the system, identifying resource and command inputs, and the system outputs; describe how the resources were processed into other forms	use the universal systems model to diagram technological systems within bio-related, communication, construction, manufacturing, and transportation technology; in each case, identify command inputs, resource inputs, processes, monitoring and feedback mechanisms, and system outputs	using the universal systems model, diagram a complex technological system involving multiple subsystems and feedback loops within bio-related, communication, construction, manufacturing, and transportation technology; identify resource and command inputs, processes, outputs, and feedback and control mechanisms

Students will use a full range of information systems, including computers, to process information and to network with different school and community resources, such as libraries, people, museums, business, industry, and government agencies.

Overview

Information systems involve graphic and electronic processes. They allow us to access information from a wide variety of sources, and to communicate with people, and with technological devices and systems. Students will have familiarity with the technological tools (computers and telecommunications) available today for accessing, networking, analyzing, processing, publishing, and communicating information.

Information systems deal with bodies of information and the communication of that information. Electronic information processing has increased the speed of transmission of information, the amount of information that can be stored, and the speed and flexibility with which information can be manipulated and retrieved. The rapid growth of information systems has had an enormous impact on society and, in particular, the workplace. Presently, about half of all American workers are involved in information processing. Traditional sources of information, such as libraries, museums, and government agencies, are now using electronic information systems. Students live in an information-oriented society and they need to be able to access and process information effectively.

Information science integrates mathematics, science, and technology. Much of the theory of information science has evolved from mathematics; statistical methods are used to analyze information, and electronic information systems are used to solve mathematical problems. Science has provided the basic knowledge about the behavior of electrons, which has been used to design communication devices, and science uses information systems to model and simulate natural phenomena. For example, models of global climate are currently being used to predict the effects of global warming. Technology provides the devices used to process information, and information systems are used to control technological processes.

In addition, information systems have applications to the social sciences, and they affect individuals, families, and society. Students need to be able to evaluate information critically and understand the potential uses and abuses of information systems. Basic literacy now extends beyond reading and writing to include the use of information systems.

The key concepts and competencies related to information systems are:

- Accessing information from a variety of sources
- Processing information
- Understanding applications and effects of information systems

At the elementary level, students	**At the intermediate level, students**	**At the commencement level, students**
access information from a wide variety of community resources; for example, computer networks/BBS's (kidnet, kidleader, etc.) with the teacher's assistance; local celebrities, experts, or other knowledgeable persons who are invited to share their experiences via speaking engagements or multimedia presentations; museums, outdoor nature centers, and industrial complexes; a wide range of materials obtained from a school's or community's libraries; sources of information available to an individual—newspapers, television, radio, libraries, teachers, parents, other students, museums, computers, etc.	write letters to representatives of industry, governmental agencies, museums, or laboratories, seeking information pertaining to a student-centered inquiry-based project; utilize local/national media to access information (television, radio, newspapers); acquire data from school weather stations, computer labs, library reference systems (card catalogs, CDs); network with museums, industry, governmental agencies, and individuals; outline procedure(s) for accessing a wide range of information pertaining to a particular topic (e.g., earthquakes, building a solar home, practical uses of fractals); interview "local" personalities/ resources (e.g. scientists, engineers, computer programmers, explorers, MST teachers, media specialists)	select, access, collate and analyze information; select appropriate mode(s) of accessing information to obtain data; obtain information by way of telecommunications; obtain information from ERIC and microfiche; utilize Internet system to share information; extract information from governmental agencies, such as: NASA, Deptartment of Education, Department of Energy and National Science Foundation; visit local/regional industry, laboratories, environmental areas and universities to obtain on-site information; join a "listserv" to obtain information from diverse geographic regions, persons, or agencies; work cooperatively with others of all ability levels; collect data from seismographs, BBS's, math/science labs
obtain, store, and retrieve information; use appropriate software, libraries, and other community resources to process information; use basic electronic input data techniques to telecommunicate a message to a distant location with the teacher's help; use word-processing software, follow standard steps in the writing process (e.g., prewriting, drafting, revising, editing, publishing) to prepare prose which addresses topics in mathematics, science, and technology	create a presentation which integrates computer and audiovisual resources to accompany a report on a researched topic—networking to take place with a variety of school and community resources such as libraries, people, museums, and government agencies; use spreadsheets and data base programs to sort, organize, record, and investigate information; prepare and send a word-processed message to a distant point via a telecommunication system without teacher assistance	select appropriate software and hardware (e.g., sensors, databases, spreadsheets) to collect, sort, analyze, and retrieve information (e.g., temperature, production accuracy, weather) over time for determining trends and patterns within the data; collaborate with individuals or groups at distant locations on telecommunications projects related to activity in mathematics, science, and technology education; create a computer-based multimedia audiovisual presentation to supplement and complement an oral report
describe the uses of information systems in homes and schools; demonstrate ability to evaluate information critically	describe applications of information technology in mathematics, science, and other technologies that address needs and solve problems in the community; explain the impact of the use and abuse of electronically generated information on individuals and families	discuss how applications of information technology can address some major global problems and issues; discuss the environmental, ethical, moral, and social issues raised by the use and abuse of information technology

Students will demonstrate knowledge of science's contributions to our understanding of the natural world, including the physical setting, the living environment, and the human organism, and will be aware of the historical development of these ideas.

Overview

Human beings have explored and reflected upon their physical surroundings and their living conditions for thousands of years. Yet it has been only in the last few hundred years that such exploration has become more systematic and has focused on empirical verification. The values that underlie modern science and its modes of inquiry have produced powerful hierarchies of knowledge concerning the physical and living environments and the human organism. Children and adolescents will understand that these major scientific concepts, principles, laws, and theories are of great importance to their personal development, their sense of civic responsibilities, and their vocational success. These ideas will be uncovered by students or revealed to them in ways that increase their understanding of the natural phenomena in the world around them and their respect for science as a powerful way of knowing.

At the elementary level, the focus will be on observation and description of natural events. At that level students are expected to examine natural phenomena and describe what they see. At the intermediate level, students will begin to provide explanations of such events. By the commencement level students will be able to provide coherent explanations of naturally occurring events in terms of key scientific theories. The approach is to move toward a progressively fuller awareness and understanding of important, naturally occurring events that affect the lives of individuals and society.

The Physical Setting

Knowledge of the physical world provides students with a sense of time and place and an understanding of the way their world works. It includes study of the universe, the solar system, and the physical environment on Earth. Knowledge of the universe grows out of direct observations, indirect observations aided by the use of tools, and analysis and inferences based on the information obtained. The universe contains billions of galaxies, each of which contains billions of stars of various types. The solar system, located at the edge of one galaxy, contains a star (the sun), planets, moons, asteroids, and comets. The relationship of Earth's location and motion to those of the sun and moon influences the physical environment in which we live in significant ways; the daily cycle of light and dark, the seasons, the tides, weather, climate, wind, and ocean currents are all affected. These in turn have profound effects on all life on Earth, including humans. The physical Earth is itself a system comprised of subsystems (the solid Earth, the waters of the Earth, and the atmosphere), which are continuously changing and interacting with the living environment. Processes on Earth, such as the movement of plates and the flow of air and water, are driven by heat energy from within the Earth and by heat generated when sunlight strikes the atmosphere and surface of Earth. Interactions between heat and other forms of energy

Explain: The verb "explain" is often used in the outcome statements, especially at the commencement level. This term refers to any student descriptions or arguments which account for observations and reveal underlying understandings of a phenomena. These understandings are referred to alternatively as mental models, conceptual or explanatory frameworks, or conceptualizations. The explanation can include any form of expression such as oral or written statements, drawings, mathematical formulations and calculations, demonstrations, and the construction of physical models.

with matter on Earth shape its surface, determine its climate, affect its atmosphere, and set the stage for life. The Earth provides humans with the resources they need to sustain life and to advance technologically.

The universe appears to contain about 100 fundamental types of matter called elements. Matter has substance (mass), occupies space, and is composed of basic building blocks called atoms. By combining in different numbers and arrangements, the limited number of types of atoms form the great variety of materials found in the world. Matter itself is one form of energy and it can interact with other forms of energy that do not have mass or occupy space: mechanical, heat, sound, light, electrical, chemical, and nuclear. Events in the universe involve transformations of one form of energy into other forms and interactions between energy and matter. In a closed system, the total amount of matter and energy do not change. Everything in the universe is in motion; all changes in motion are due to the action of forces. Two forces, gravitational and electromagnetic, are important in the everyday world, but other forces operate within the nuclei of atoms. Moving objects behave according to certain general principles or laws. Vibrations and waves are complex types of motion that can be described by frequency and displacement or wave length. Understanding the structure and behavior of matter provides students with a basis for understanding the physical setting in which they live.

The key concepts and competencies related to the physical setting are:

- The structure of the universe and solar system, the principles that govern them, and changes in them over time
- The subsystems of the Earth and the principles that govern their interaction
- The structure of matter
- Forms and transformations of energy
- Natural forces
- Motion of objects

At the elementary level, students	**At the intermediate level, students**	**At the commencement level, students**
observe and describe patterns of daily, monthly, and seasonal changes in the physical world of everyday experience	create models, drawings, or demonstrations to describe how the arrangement and movement of objects in the solar system; explain daily, monthly, and seasonal changes on Earth	explain complex phenomena, such as apparent motion of the planets, annual traverse of the constellations, tides, variations in day length, and current theories about the origin of the universe and solar system
describe the three major subsystems of the physical Earth, including the major landforms and rock types, the water cycle, and weather patterns	recognize that the subsystems of the Earth are continuously evolving, changing, and interacting; describe the movements of the tectonic plates, volcano and earthquake patterns, the rock cycle, weather changes, and long-term climate changes	explain the movements of the Earth's plates and weather patterns in terms of heat energy and density; describe how scientists estimate the age of the Earth; relate weather and climate to ocean currents and land masses; explain long-term climate changes
observe and describe properties of materials; compare appearance of materials when seen with the naked eye and when magnified; observe and describe physical and chemical changes, including matter phase changes	observe and describe more complex properties of materials, such as density, conductivity, and solubility; use atomic and molecular models to explain common chemical reactions; observe and apply the principle of conservation of mass; use kinetic molecular theory to explain matter phase changes	explain the properties of materials in terms of the arrangement and properties of the atoms of which they are composed; apply the principle of conservation of mass to chemical reactions; use kinetic molecular theory to explain rates of reactions and the relationships among temperature, pressure, and volume

At the elementary level, students	At the intermediate level, students	At the commencement level, students
observe and describe common forms of energy and the changes in objects when they interact with energy; observe energy changes in common chemical reactions	explain the sources and transformations for the energy we use every day; explain heating and cooling; explain energy changes and chemical reactions; describe the properties of sound, light, magnetism, and electricity; describe how energy is obtained from nuclear reactions; observe and apply the principle of conservation of energy	observe and describe how various forms of energy travel; explain heat in terms of kinetic molecular theory; construct simple devices using sound, heat, light, magnetism, and electricity; explain the uses and dangers of radioactivity; describe the electromagnetic spectrum; explain the conservation of mass and energy
observe and describe the effects of common forces, such as gravity, electrical charge, and magnetism on objects; recognize that forces can operate over distance	relate strength of gravitational force to the masses of objects and the distance between them; observe and describe electromagnetic forces; use electric force to explain the structure and reactions of atoms; recognize that nuclear forces are stronger than electromagnetic forces	explain the role of the force of gravity in the universe and solar system; use electric force to explain chemical reactions; build and use devices using electromagnetic forces; explain why nuclear reactions release much more energy than chemical reactions
observe and describe objects in motion; use simple machines to move objects	explain the effect of friction on the motion of objects, explain how objects fall to Earth, demonstrate and explain changes in speed and direction of objects; use and explain simple machines	explain and predict the motion of objects, including falling objects, with and without friction, circular motion, and trajectory; calculate work done and efficiency of simple machines; describe and explain oscillatory motion

The Living Environment

As a result of its interactions with the physical environment of Earth, the living environment constitutes a fourth subsystem of the Earth system. Knowledge of the living environment provides students with an understanding of their place in the natural world and of how humans can shape the environment for the benefit of themselves and other living organisms. The living environment consists of millions (perhaps even tens of millions) of different types of organisms, all of which carry out the same basic functions that maintain life and which evolved from common ancestors about three billion years ago. One way scientists classify the great variety of life on Earth is on the basis of similarities and differences in structure. All living things are dependent upon the physical environment and, directly or indirectly, on all other forms of life. Together, the physical and living environments in an area constitute a system, an ecosystem, and exhibit the properties characteristic of natural systems. Energy flows through an ecosystem from the Earth's primary source of energy, the sun, to organisms that can transform light energy into chemical energy. Other organisms then depend upon this chemical energy, in food, to survive. While energy continually flows to Earth from the sun, matter on Earth is limited. Over periods of time varying from days to eons, matter cycles between the living and nonliving environment. The information required to carry out the life functions is encoded in chemicals in the nuclei of cells and passed from generation to generation. A complex interplay between variations in the code and environmental factors results, over time, in changes in living organisms.

The key concepts and competencies related to the living environment are:

- The properties that distinguish living from nonliving things
- The organization of living things into subsystems
- The diversity of life
- How genetic information is passed from generation to generation
- How living things have adapted to the physical environment

- The life cycles of organisms and how they reproduce and develop
- How living organisms have evolved
- How organisms sustain life and maintain a dynamic equilibrium
- The interactions and interdependencies of life forms

At the elementary level, students	At the intermediate level, students	At the commencement level, students
observe and describe examples of living and nonliving things, common plants and animals, and life processes common to all living things	describe the properties that distinguish living from nonliving things	explain the properties that distinguish living from nonliving things
observe and describe how objects appear when magnified as compared to when seen with the naked eye	describe the levels of organization in organisms and explain that the subsystems interact to support the living system	explain how the parts of an organism are organized to maintain life; compare an organism to a system
observe and describe variation among individuals of the same kind; describe the characteristics of the five main groups of vertebrate animals	observe and describe representatives of the five kingdoms and of the major animal phyla	describe the diversity of life and explain why biologists classify organisms
recognize that some traits of living things are inherited while others are acquired or learned	describe how genetic material is passed from generation to generation and explain simple patterns of inheritance	explain how the structure and replication of genetic material result in offspring that resemble parents and how patterns of inheritance can be used to determine genetic makeup and predict characteristics of offspring
observe and describe how the structures of plants and animals are adapted to the functions they perform	describe examples of plant and animal adaptations	explain the adaptiveness of structures in living organisms
observe and describe the healing of cuts and bruises and the growth of organisms; explain that reproduction of most plants and animals involves two parents; observe and describe development of common organisms	observe and describe cell division; describe the differences between asexual and sexual reproduction; describe the stages of development of multicellular plants and animals	describe how cells divide to form new cells and how organisms reproduce more of their kind; describe the development of organisms from fertilized egg to mature adult
observe and describe fossils; relate variation within a species to advantages and disadvantages for survival	describe the four major geological eras and the dominant organisms characteristic of each; explain the causes and significance of competition within species	explain and interpret the fossil record and the origin and extinction of species; explain the mechanisms and patterns of evolution
observe and describe how common organisms carry out basic life functions; observe and describe behavior in common organisms	compare the way a variety of representative organisms carry out the basic life functions and maintain a dynamic equilibrium; describe and explain the behavior of organisms	explain how organisms carry out the basic life functions; explain the basic biochemical processes in living organisms; observe and identify common types of behavior in animals and explain their functions and survival value
provide examples of the interdependence of animals and plants; recognize the importance of the sun as an energy source and of recycling; recognize the existence of climate regions and associate them with characteristic plants and animals	illustrate food chains and recycling of materials in nature; describe the process by which green plants make food; describe examples of natural disturbances to the environment and their consequences; describe the major biomes of the world and the dominant plants and animals of each	explain what sustains life on Earth; explain photosynthesis; cite reasons why populations of organisms do not increase indefinitely; explain why it is important to preserve species and habitats; describe how the environment changes over time and how it responds to disturbances; explain the geographic distribution of plants and animals

The Human Organism

Humans share with other living organisms the same basic needs and use the same basic functions to satisfy these needs. The structures and functions of the human body, however, differ in specific ways from those of other species, and humans are unique among all living things in their curiosity, ability to learn, use of language, and capacity for abstract thought, creativity, and inventiveness. Although humans are closely related to the higher primates, they have a different social structure and exert greater control over their environment through technology. Variations among groups of people exist, but all of the five billion people who now live on Earth constitute one species. Despite the great similarities among people, each individual is unique. As part of the process of maturing, students need to understand both what they have in common with other people and other species, and how they are different. Knowledge of the human life cycle and of how their bodies and minds work and develop helps students function in relation to others, maintain physical and mental health, and understand their place in the natural world. Human activities impact the Earth's systems to a greater extent than those of any species in the history of the Earth. Understanding the human organism and its relationship to the living and nonliving environment is necessary to ensure adequate resources and a healthy environment for future generations of humans and of other species.

The key concepts and competencies related to the human organism are:

- The structure and function of the organs and subsystems of the human body
- How humans obtain and process energy
- How humans maintain health
- The human life cycle
- Patterns of human inheritance
- How the human species relates to other living organisms
- How humans depend upon and interact with their environment
- The unique characteristics of humans

At the elementary level, students	At the intermediate level, students	At the commencement level, students
describe the main parts and basic functions of the human organ systems	explain the functioning of the major organ systems and their interactions	describe and explain the organization of the human body into subsystems; describe and explain the functioning of the major organ systems; describe how the body maintains a dynamic equilibrium
observe and describe the effects of exercise on themselves	measure changes in the functioning of systems in response to exercise; explain the need for a constant supply of energy	explain the function of the human respiratory system and the process of cellular respiration
describe the requirements for a well-rounded diet and practice good health habits	describe the roles of the major nutrients, vitamins, and minerals in maintaining health and promoting growth; describe the role of the immune system in preventing and combating disease	explain disease as a failure of homeostasis; identify the major types of disease and their causes; explain why vitamins and minerals are necessary to maintain health; explain the parts and functions of the immune system
describe the major stages in the human life cycle	describe reproduction and development in humans, including changes in the human body as it matures and ages	describe the formation of sperm and eggs, fertilization, and the development of the human fetus, the stages of pregnancy, health habits important during pregnancy, birth, and contraceptive methods

At the elementary level, students	At the intermediate level, students	At the commencement level, students
identify examples of human traits that are inherited and those that are acquired; recognize that there is genetic continuity between generations	trace patterns of inheritance for some common human traits; explain the role of genetic counselors	use genetic models to predict characteristics of offspring; describe the technology of genetic engineering; discuss ethical issues arising from genetic counseling, genetic therapy, and amniocentesis
recognize the place of the human species in nature and its relationship to other organisms	cite evidence for relating humans to other primates	explain the place of the human species in the biological classification systems and describe in general terms the evolution of the human species
provide examples of how humans depend upon the living and nonliving environment for survival	explain the dependence of humans on other life forms; give examples of how humans have affected the environment	explain how humans affect the environment and effects of human population growth and technological development on the environment; discuss the responsibilities of humans toward other living things
identify unique characteristics of humans, observe and describe patterns of human behavior	compare human behavior with that of other animal species; provide examples of how humans have used technology to improve their lives	explain how human behavior differs from that of other animals and how that is believed to have affected evolution of the human species; describe human progress in controlling the environment

Students will acquire the knowledge and skills related to the tools, materials, and processes of technology to create products, services, and environments in the context of human endeavors such as bio-related technologies (agriculture, health), manufacturing, construction (shelter and other structures), transportation, and communication.

Overview

Technology is as old as the human race itself and is an integral part of our social structure. People are dependent upon technical means for survival and quality of life. Nations are dependent upon technological development for their economic competitiveness and national security. Students will understand and demonstrate abilities in design, engineering, invention, innovation, and other problem-solving strategies related to technological resources and management.

Knowledge of the technological world will enable people to function effectively in their roles as consumers, voters, workers, employers, and family members. The study of technology will help to provide a technologically creative and competent citizenry that can contribute to human-centered technological development (that is, development without unacceptable damage to humans or to the natural environment).

Our technological knowledge base has accumulated over time, beginning with knowledge gleaned from empirical practice in prehistoric times to modern technological knowledge that is often but not always driven by science. The relationship between science and technology is a synergistic one. Much of early science was predated and informed by related technology; the invention of the steam engine, for example, informed the science of thermodynamics, and glassmaking preceded the science of chemistry. Technological tools such as the microscope and telescope have contributed enormously to our understanding of the natural world.

Likewise, scientific discoveries have stimulated technological developments such as lasers, integrated circuits, and genetic engineering, and most of the modern "high" technologies involve a strong science base. However, science-driven technologies are comparatively recent. Even modern high-technology industries, in order to remain competitive, must rely on efficient production techniques and refined design procedures, involving considerably more knowledge than the application of scientific concepts alone.

Technology as Knowledge and Process

Technology can be defined as the application of knowledge and the use of tools to transform resources in order to satisfy human needs and wants. Technology is both a body of knowledge and a process of purposeful application of knowledge. The knowledge base of technology relates to the tools, resources, and processes used to create products, systems, and services demanded by humans. The process of technology—design and problem solving—is what makes the knowledge base useful. The knowledge base and the design and problem-solving process are woven together in technological endeavors.

Technological design problems can complement and contextualize the study of mathematics and science and provide students with opportunities to synthesize much of their learning. Real-world problem solving provides the context for conceptual learning to be applied and for technological design activity to occur.

Standard 5 focuses on the technological knowledge base—knowledge about the nature, evolution, and impacts of technology, as well as the tools, resources, and processes which people employ while engaging in activities such as bio-related technology, communication, construction, manufacturing, and transportation. These activities are found in all cultures and are implemented to adapt the natural environment to human needs and wants. The process component of technology, that of designing solutions to problems, is addressed through Standard 1 (see engineering design).

The key concepts and competencies related to technology are:

- The nature and impacts of technology
- The history and future of technology
- Technological tools and machines
- Technological resources
- Technological processes (communication, manufacturing, construction, transportation, energy and power generation, bio-related technologies)
- Technology, national security, and economic competitiveness

At the elementary level, students

explain how technology seeks to satisfy human needs through construction of shelter, transportation of people and goods, production of clothing and other necessities, facilitation of communication, improvement of health care, enhancement of the growth of plants and animals, and development of specialized and adaptive devices for people with special needs; identify daily routines that involve the use of technology; describe how familiar technologies have positive and negative impacts on people and the environment

At the intermediate level, students

explain how people's routines are influenced by technology and how much of human progress has occurred as a result of technological development; document how technological progress has been the result of cumulative work over many centuries of men and women from various cultures and races in every part of the world; model technological advances that have improved the quality of life for individuals, including those with special needs; explain through examples how the impacts of technology can be intended, unintended, desired, and/or undesired; describe how technology is neither good nor evil but can be helpful or destructive depending upon how people employ it; explain that although technology solves many problems, new problems may result from its use

At the commencement level, students

explain how rapidly changing technology affects global competition and jobs; assess needs and research, design, and model a technological device, service, or system that might be used to assist elderly or disabled persons; explain through examples how technological impacts can be multidimensional (e.g., economic, social, environmental, political)

At the elementary level, students	At the intermediate level, students	At the commencement level, students
document the history of technological change, and identify technological developments that have significantly accelerated human progress, such as the development of writing in 3500 B.C., or printing with movable type in 1450 A.D.; identify technological inventions and innovations that have been developed by males and females from various racial and cultural backgrounds; construct models of early tools or devices and describe how they have contributed to human progress; describe imaginatively how technology might affect our lives 50 years in the future	demonstrate how the evolution of technology led to the shift from an agriculturally based, to an industrially based, to an information-based society; describe through the use of technological time lines, how technology is growing exponentially at a faster rate today than ever before in history; explain the differences between inventions and innovations, and model examples of technological innovations and inventions that satisfy human biological, physical, and psychological needs; trace the evolution of complex technological tools such as cameras or computers, from simple beginnings to their present state; explain how emerging technologies will create new jobs and make others obsolete	describe how technological developments have been influenced by the culture of a society and by the resources available to that society; identify emerging technologies in areas of bio-related, communication, construction, manufacturing, and transportation technology; describe the process through which an invention is patented; describe products or processes patented by males and females of various races and cultures, and explain the impact of their endeavors
select and use simple tools and machines to process materials, energy, and information, and to model solutions to design problems; explain how tools extend human capabilities	identify, explain the function of, and use a range of tools and machines including measuring tools, hand tools, machines, electronic tools and instruments, and optical tools to implement solutions to technological design problems in a variety of technological contexts (bio-related technology, communication, construction, manufacturing, transportation); use instruments and tools to do simple troubleshooting on common mechanical and electrical systems, identifying and eliminating some possible causes of malfunction	identify and use a wide range of contemporary tools, machines, measuring instruments, computer-based tools, and data-capturing probes to process and measure materials, energy, physical phenomena, and electronic signals; describe, select, and use a range of complex tools, machines, and equipment to solve problems in a variety of technological contexts; skillfully and safely use a wide range of tools and instruments to analyze, adjust, and maintain mechanical, electronic, hydraulic, pneumatic, and electrical systems
recognize and describe how various material resources have different properties and understand that some are better than others for a specific use; use a variety of materials (e.g., wood, metal, fabric, plastic, clay) to make simple products; describe characteristics of and differences among familiar materials; describe how some materials can be recycled, while others cannot; describe how seven types of resources (people, information, tools and machines, materials, energy, capital, and time) are necessary in any technological endeavor; identify and describe scarce and plentiful resources	describe how the choice of materials depends upon their properties and characteristics, and how they interact with other materials; perform materials tests (e.g., hardness, tensile strength, conductivity), evaluate the results and make suggestions about the appropriate uses for these materials; describe materials that are biodegradable and those that are not; explain the purposes, benefits, and costs of recycling; recycle appropriate materials into useful products; identify and classify resources within the seven resource categories; explain why certain resources on Earth are limited and why people must use these resources wisely, and dispose of them responsibly; explain how synthetic materials can help reduce the depletion of some scarce natural resources	identify, test, and describe the properties of a wide range of resources including synthetic, composite, and biological materials, various energy sources, and forms of information; design, develop, and use a material-testing system to test materials for a specific property or characteristic; identify and appraise current issues on resource management and model a resource management system (e.g., a waste management system, a cogeneration system), considering safety, cost, and environmental and political concerns; explain the benefits and economic costs associated with the use of people, capital, and time in technological ventures; identify and describe alternatives to scarce and costly resources, and explain tradeoffs in terms of the properties of resources, availability, ease of processing and disposal, and economic considerations

At the elementary level, students	At the intermediate level, students	At the commencement level, students
identify, describe, and use technological processes to:	identify, explain, and use a wide range of technological processes and demonstrate the ability to:	identify, explain, design, use, and evaluate a wide range of technological processes, and demonstrate the ability to:
—communicate messages graphically and electronically, using drawings, computer hardware and software, and simple electronic devices	—identify, describe, and use a wide range of technological processes to graphically and electronically communicate information; explain how communication errors can be reduced	—select and use combinations of graphic and electronic communication processes and explain and correct errors in encoding, transmitting, and decoding messages; design and communicate messages containing integrated written, audio, and video portions for purposes of information dissemination, persuasion, entertainment, and education
—produce artifacts from resistant materials (e.g., wood, plastic), using cutting and shaping tools	—identify, select, use, and explain the choice of appropriate material conversion processes (i.e., separating, forming, conditioning, and combining) used in production processes; define the steps in a manufacturing process; organize and operate a mass production enterprise to produce a simple product; explain how modern technology reduces manufacturing costs and produces more uniform, higher quality products	—identify, suggest, and explain forming, separating, conditioning, and combining processes that are used in implementing a wide range of complex products and structures; explain how manufacturing processes have been changed by improved tools and techniques based upon changes in scientific understanding, increases in the forces that can be applied, and the temperatures that can be reached, and the availability of electronic controls that make operations more rapid and consistent; design, organize, finance, and operate an automated mass production enterprise involving a combination of material conversion processes to produce products
—design and build models of structures (e.g., residences, skyscrapers, bridges, tunnels, airports)	—identify, explain, and use construction processes to model site preparation, building, and finishing a structure	—through research, identify and suggest how contemporary and nontraditional construction processes (e.g., fabric structures, geodesic domes, foam structures) are used to create a structure, and create a model of a structure blending traditional and contemporary techniques
—transport people and goods, using boats, automobiles, trucks, trains, and airplanes	—identify and describe a wide range of technologies used to move people and products on land, water, and in the air; model a land, marine, and air transportation system; explain the operation of systems which carry people and cargo without vehicles (e.g., pipelines, conveyors)	—identify and explain how intermodal transportation technologies convey people and products globally; modify and combine intermodal transportation processes into a model that transports people and products efficiently with minimal risk to the cargo and to the environment

At the elementary level, students	**At the intermediate level, students**	**At the commencement level, students**
—provide energy and convert it into different forms; use mechanical linkages and gears to transmit energy	—identify, describe, and model energy processes used to convert and transmit mechanical, electrical, chemical, light, heat, and nuclear energy; explain through modeling how transportation systems convert energy into motion; describe limited (e.g., fossil fuels), unlimited (e.g., solar, gravitational) and renewable (e.g., biomass) energy sources	—select, combine, and use a range of energy-production processes to create an energy-producing system designed to address a particular need; explain how decisions to slow the depletion of energy sources through efficient technology can be made at many levels, from personal to national, and understand that these decisions can involve tradeoffs of economic costs and social impacts; explain how industrialization brings an increased demand for energy usage which contributes to a higher standard of living in the industrially developing nations but also leads to more rapid depletion of the Earth's energy resources and to environmental risks associated with the use of fossil and nuclear fuels
—produce and preserve food products	—identify and describe biotechnical processes used in manufacturing, agriculture, and health care; design systems that use biotechnical processes (e.g.,hydroponics and water purification); explain how ergonomic design improves people's ease and comfort in using products; design and model a technological device for individuals having special needs	—identify, describe, and use a range of bioprocessing systems; describe technological processes which could adversely affect the environment of humans (e.g., high-noise concerts, poor lighting) and suggest improvements which could reduce undesirable outputs; model an ergonomically-designed technological device or system matched to anthropometrics (human dimensions and limits of movement)
describe how a nation's strength is related to its level of technology and identify technologies that affect national security; identify major commercial producers and distributors that directly affect their lives; identify companies that have produced innovative products and/or services	identify and describe technological factors which differentiate weak and strong nations; explain how national security is dependent upon both military and nonmilitary applications of technology; identify successful companies and explain the reasons for their commercial success	explain how one country (or group) has used technology to prevail over another (e.g., through colonization and military victory); explain why technologies do not remain a monopoly for long due to the ease of technology transfer; describe how nations which have been technologically innovative have historically been able to defend their national sovereignty; discuss the role technology has played in the operation of successful U.S. businesses and under what circumstances they are competitive vis-a-vis other countries; explain how technological inventions and innovations stimulate economic competitiveness, and how, in order for an innovation to lead to commercial success, it must be translated into products and services with marketplace demand; explain how new management techniques (e.g., computer-aided engineering, computer-integrated manufacturing, total quality management, just-in-time manufacturing) have reduced the length of design-to-manufacture cycles, have resulted in smaller, more flexible factories, and have improved quality and customer satisfaction

STANDARD 6—MATHEMATICS

Students will understand and use basic mathematical ideas, including logic, number sense and numeration concepts, operations on numbers, geometry, measurement, probability and statistics, algebra, and trigonometry; and be familiar with their uses and application in the real world through problem solving, experimentation, validation, and other activities.

Overview

Mathematics is the discipline that provides concepts, principles, and reasoning methods for problem solving and decision making involving questions of change, dimension, quantity, shape, and uncertainty. Mathematics is a language using symbols and numbers to express and verify relationships fundamental to both pure and applied mathematics. Logic and critical thinking skills play a major role in the development of mathematics.

Mathematics is part of our social, technical, and academic lives. Social mathematics is that mathematics needed for personal living, aesthetic appreciation, and effective citizenship in our society. Technical mathematics refers to the area of mathematics deemed necessary and applicable to skilled work in business, industry, technology, and the social, biological, and physical sciences. Academic mathematics includes the formally structured mathematics that provides the basis for an understanding of the various complex processes forming the theoretical basis of formal mathematics.

Our nation and the world are becoming more mathematical as we change from industrial to informational societies. Incredible changes are occurring in the field of mathematics and the pace of change continues to increase even as we go about our daily lives. Jobs today require more sophisticated mathematics than ever before; competition for both jobs and markets has become worldwide and international in scope. For our children to lead satisfying and fulfilling lives and for them to be able to compete successfully for jobs in an international workplace with their peers from around the world, it is necessary to help them acquire the skills and understandings that are appropriate for the world in which they will live and work after completing their formal education.

Major ideas to be emphasized in implementing this standard include problem solving, reasoning and critical thinking, communication, the social nature of learning, the use of technology, the personal construction of knowledge, and mathematical connections.

The key concepts and competencies for the mathematics standard are related to the following areas of study:

- Logic
- Number sense and numeration concepts
- Operations on numbers
- Geometry
- Measurement
- Probability and statistics
- Algebra
- Trigonometry

Progression of Student Learning

Elementary

Students are engaged in "doing" mathematics by conducting experiments, predicting results, and seeing mathematics as part of their real world. Elementary mathematics classrooms should have children involved in and excited about what they are doing; mathematics should be viewed by them not only as "how to" but also as "why" and "what if." The operations of mathematics as processes that can be modeled with physical objects should be stressed. Although computation continues to be of high importance, development of computational techniques that make sense to the student is critical. The other areas of study in mathematics should also be explored at this level; the foundations for students' later work can be strengthened by performances that indicate how well they understand concepts and skills rather than how many skills they have acquired.

Intermediate

Students should continue to improve computational skills and understandings, including the concepts of fractions and decimals. Students should be provided with experiences that intuitively introduce them to ideas of ratio, proportion, and percent. Mathematics should continue to be experienced in the context of real-world problems, addressing the curiosity of students while increasing the opportunity for transfer of knowledge. Student performance at this level should include a facility with different technologies that act as tools to help solve mathematical problems while aiding the student in the exploration of new content.

Commencement

Students should be able to synthesize mathematical ideas so as to exhibit abilities in reasoning, problem solving, and communication. The application of various branches of mathematics to real-world problems and situations should be stressed at this level. Also, use of technology in the investigation of mathematics and in the solution of problems is an expected occurrence at this level.

Logic

Logic is included as an area of study as a necessary, desirable, and enjoyable prelude to future work in mathematics, in other disciplines, and in everyday living. The logical processes of reasoning are something that can and should be taught. Students should have many experiences requiring them to use mathematical reasoning, as it is essential to concept and skill development, problem solving, and justification of mathematical conclusions.

At the elementary level, students

draw logical conclusions about mathematics; use models, known facts, properties, and relationships to explain their thinking; justify their answers and solution processes; use patterns and relationships to analyze mathematical situations

At the intermediate level, students

recognize and apply deductive reasoning; understand and apply reasoning processes; make and evaluate mathematical conjectures and arguments; appreciate the use and power of reasoning

At the commencement level, students

recognize and apply inductive reasoning; make and test conjectures; follow and judge the validity of logical arguments; construct simple arguments, using the laws of logic

Number Sense/Numeration Concepts

In order for students to make use of numbers in the real world, they must have a good understanding of what numbers are, recognize relationships among numbers, and know basic concepts pertaining to various types of numbers. Students should begin with the natural numbers and continually extend their understandings through the entire real number system. Numbers and number theory provide the underlying structure of mathematics.

At the elementary level, students

construct number meanings for whole numbers and simple fractions; model numbers and number relationships for whole numbers and simple fractions, using concrete objects; show relationships among various numbers and number concepts; make application of numbers and numeration concepts

At the intermediate level, students

construct number meanings for fractions, decimals, and integers; extend number and numeration concepts to include fractions, decimals, and integers; develop concepts of ratio, proportion, and percent; apply and solve problems, using ratio, proportion, and percent

At the commencement level, students

construct number meanings for all real numbers; understand the structure and development of the real number system; relate and apply number and numeration concepts to other areas of the curriculum; use number and numeration concepts to solve a wide range of problems

Operations on Numbers

Students should develop meaning for operations through modeling with manipulative materials and relating mathematics language and symbolism to informal language. They should use appropriate technology when performing numerical computations. Proficiency with, and understanding of, operations should be embedded in a wide variety of problem situations. Students should be able to ascertain what method (e.g. mental, paper and pencil, calculator) should be used in a given situation requiring computation.

At the elementary level, students

use whole numbers; model, explain, and develop reasonable proficiency with basic facts and algorithms; model the basic operations of whole numbers, using manipulative materials; connect mathematical language and symbolism of the basic operations to intuition and informal language; make estimates involving computations; analyze and solve basic problems present in the local environment involving computations

At the intermediate level, students

use fractions, decimals, and integers; model, explain, and develop reasonable proficiency with basic algorithms; use concrete materials to model the basic operations with fractions, decimals, and integers; apply basic algorithms and the conventional rule for order of operations in performing routine calculations; use estimation to check the reasonableness of results obtained by conventional algorithms or modern technology; solve basic problems involving integers, fractions, and decimals in a wide array of situations

At the commencement level, students

calculate with the set of real numbers, using a variety of computation techniques; select and use the appropriate method for computing; analyze and solve problems requiring a multiple use of computational skills; use, when appropriate, estimation techniques to approximate the solution to problems; solve a variety of complex problems involving the real number system

Geometry

Geometry is an important component of the mathematics curriculum. Geometric knowledge, relationships, and insights are useful in everyday situations and are connected to other mathematical topics and to other subject areas. Geometry helps us model and describe, in an orderly manner, the world in which we live. Geometry provides students with the tools to gain insight into various branches of mathematics and to solve real-world problems.

At the elementary level, students

demonstrate an awareness of geometry in their environment; explore and compare the attributes of two- and three-dimensional figures; explore patterns made up of geometric shapes; investigate and predict the results of combining, subdividing, and changing shapes; relate geometric concepts to everyday situations

At the intermediate level, students

explore ways in which geometry is used in the real world; use basic ideas of transformations to observe the preservation of size and/or shape; classify two- and three-dimensional figures based on particular attributes; construct geometric conclusions, using logical reasoning; use geometric ideas to analyze problems involving geometric concepts

At the commencement level, students

relate geometric principles to real-world phenomena; demonstrate the understanding of transformations with respect to congruence and similarity in everyday experiences; analyze patterns in two and three dimensions; construct convincing arguments, using geometric concepts; apply geometric ideas in the solution of problems; from given assumptions, deduce properties of, and relationships between, geometric figures; make coordinate representations of geometric figures and concepts; deduce properties of figures, using transformations and coordinates

Measurement

Measurement is of central importance to the curriculum because of its power to help children see that mathematics is useful in everyday life. Children should learn to measure carefully by actually measuring objects. Measurement is a valuable area for showing the connection of mathematics to other disciplines. Measurement activities should begin with using nonstandard measuring tools. As students see a need for standardization, more traditional measurement tools should be presented.

At the elementary level, students

understand that measurement is approximate, never exact: select appropriate standard and nonstandard measurement tools in measurement activities; be familiar with the metric system of measurement; explore the attributes of area, length, capacity, weight, volume, time, and temperature; make estimates of measurement, using formal and informal methods; compute quantities such as length and perimeter using nonstandard and standard units

At the intermediate level, students

understand that measurements to a specific degree of accuracy can be taken; select appropriate measurement tools to measure to the degree of accuracy desired in particular situations; be able to measure and compute measurement quantities, using both English and metric systems of measurement; informally derive and use formulas in measurement activities; solve a wide array of problems, using measurement concepts; compute quantities such as area and volume, using standard units of measure

At the commencement level, students

relate the concept of precision of measurement with accuracy of a calculation, using measurements; use instruments and procedures to make indirect measurements; use dimensional analysis techniques in problems involving measures; validate formulas used to compute measurements; solve a wide array of problems in the context of the mathematics, science, and technology curriculum; compare relationships pf perimeter, area, and volume as the lengths of the sides of figures vary

Probability and Statistics

The language of probability has become a part of everyday life. Understanding this language has become an important outcome of school mathematics. Students should be able to interpret statements given in the language of probability. The study of probability should progress from experimental probability to theoretical probability. Students should be introduced to simulation techniques associated with probability. The study of probability provides a rich setting for problem solving. There is a need for productive and informed citizens to be able to make sense of increasing flows of information data in vocational, recreational, and everyday activities. Having available an understanding of essential statistical procedures provides people with a powerful means for managing data and assists them in making reasonable decisions and interpretations. Students should make connections between statistical information and probability ideas.

At the elementary level, students

explore concepts of chance; conduct experiments involving chance; relate probability to students' everyday experiences; model probability concepts, using concrete objects; collect, organize, represent, and describe data; make graphic records of statistical data drawn from newspapers, magazines, polls, appropriate activities in other subject areas, etc.; formulate and solve problems that involve collecting and analyzing data; analyze results and make predictions from a statistical study

At the intermediate level, students

distinguish between empirical and theoretical probabilities; model situations by devising and carrying out experiments and simulations to determine probabilities; appreciate the power of using a probability model by comparing experimental results with mathematical expectations; make predictions; appreciate the pervasive use of probability in the real world; systemically collect, organize, describe, and interpret data, including grouped data as well as individual data; use sampling in statistical studies; use measures of central tendencies to analyze data; extrapolate information from a set of data in numeric or graphic form

At the commencement level, students

use experimental or theoretical probability, as appropriate, to represent and solve problems involving chance; create and interpret discrete probability distributions; understand the concept and use of randomness; use simulations, including computer simulations, to estimate probabilities; understand a normal distribution; solve problems involving probability concepts; recognize that as the size of n increases in a probability experiment, the experimental probability approaches the theoretical probability; design and conduct statistical studies, interpreting and communicating their findings; draw inferences from charts, tables, and graphs that summarize data; differentiate between normally distributed and skewed data; appreciate statistical methods as powerful means for decision making; determine measures of dispersion for a given set of data; use computer software to model data from the real world

Algebra

Algebra is the language through which much of mathematics is communicated. It also provides a means of operating with concepts at an abstract level and then applying them. The study of algebra provides students with the skills that will be useful as they continue to study mathematics. Algebra is a tool that allows the user to explore relationships in more general terms, and is a language that enables the user to express ideas in symbolic form.

At the elementary level, students

explore number sentences; using whole numbers, investigate number properties involving operations; investigate quantities that vary; describe the effect of change in number relations; use concrete models to model correspondence

At the intermediate level, students

model the solution of simple equations, using concrete materials; graph linear relationships; develop procedures for computing with integers; use variables; write and solve equations; compare direct and indirect variation; select and use appropriate technologies to investigate algebraic concepts

At the commencement level, students

use algebraic and graphic techniques in the solution of equations; compare and contrast direct and indirect variation, including the use of graphs; explore functions that depict real-world phenomena; use algebraic techniques in the solution of problems; relate algebraic ideas to coordinate geometry; solve problems involving direct relationships; select and use appropriate technologies when solving problems involving algebraic concepts

Trigonometry

Trigonometry has its origins in the study of triangle measurement. Many real-world problems require the solution of triangles. In addition, many mathematical topics require trigonometric ratios. These ratios give rise to trigonometric and circular functions, which can be used as mathematical models for many periodic real-world phenomena. The study of trigonometry is a rich source for the solution of realistic problems.

At the elementary level, students

investigate patterns with triangles, using devices such as the geoboard

At the intermediate level, students

investigate the relationships among the sides of similar triangles; explore relationships with similar triangles in the solution of problems

At the commencement level, students

relate the invariance of the ratios of corresponding sides in similar right triangles to the trigonometric functions in a right triangle; apply trigonometry to problem situations involving right triangles; use calculators to access the trigonometric functions of a given angle

Students will understand the relationships among mathematics, science, and technology, identify common themes connecting them, and apply these themes to other areas of learning and performance.

Overview

A natural connection exists among the three disciplines of mathematics, science, and technology. Whole areas of mathematics have developed from one or another of the empirical sciences. Conversely, some areas of science developed from the knowledge of pure mathematics and the need to understand the theoretical underpinnings of technological systems. Technology uses mathematics and science knowledge to turn resources into products, systems, and services. Students' integrated projects, which require application of knowledge from the three disciplines, are intended to help students appreciate the interconnectedness of the disciplines, the ethical and social dimensions that transcend each discipline's boundaries, and the habits of mind associated with each discipline.

Individually and together, mathematics, science, and technology provide insights into philosophical and practical areas of human concern. One way to provide experiences that integrate mathematics, science, and technology is to adopt and implement curricula that are organized around themes. Students will be able to access and process contributions from each discipline and integrate them with those from other disciplines for use in problem solving. They will develop a useful personal understanding of such conceptual themes as equilibrium, modeling, optimization, patterns of change, scale, and evolution. Such themes lend themselves to observation, to explanation, and to design. Students will be encouraged to transfer their knowledge and through metaphor or analogy, to better understand the unfamiliar by likening it to the familiar.

Throughout history, mathematics, science, and technology have been closely linked, as developments in one spurred advances in another. Galileo contributed to the rise of modern science when he pioneered the use of mathematical models. His discovery of the moons of Jupiter was possible only because of the invention of the telescope. The telescope, in turn, has helped scientists learn much about the solar system and universe. Although each of the fields has its own character and methodology, there are numerous ways in which they overlap. Traditionally, however, mathematics and science have been taught as separate disciplines with minimal opportunities for students to apply learning in one to the other, and the study of technology as an integrative force has only recently been introduced as a field of study in schools. Most problems in the real world require interdisciplinary solutions; thus, educating students requires that they have an understanding of the interconnectedness of mathematics, science, and technology. Additionally, mathematics, science, and technology exist in the context of society and are constantly interacting with it.

The key concepts and competencies related to the themes standard are:

- The interconnectedness of mathematics, science, and technology
- The major conceptual themes common to mathematics, science, and technology: equilibrium, modeling, optimization, patterns of change, scale, and evolution
- The relationship of mathematics, science, and technology to society

At the elementary level, students	At the intermediate level, students	At the commencement level, students
give examples of how people use mathematics, science, and technology to solve problems, of tools that have been used to expand knowledge of mathematics, science, and technology, and of how scientific and mathematical knowledge has led to the development of technological devices	illustrate how people use scientific inquiry and mathematical models to design solutions to technological problems; trace the development of a technological device, explaining its dependence upon scientific and mathematical knowledge; illustrate how the availability of a technological tool has led to new knowledge in science and mathematics	explain how mathematics, science, and technology are used to solve a problem; demonstrate the relationship of mathematics and science to a technological product; research how a technological tool has led to new knowledge in mathematics and science
give equilibrium examples from mathematics, science, and technology; use models to simulate objects, events, and processes in the real world; describe how making tradeoffs is necessary to choose the best overall solution/decision; observe and describe patterns of change; distinguish between absolute and relative scales; observe and describe examples of changes over time	use models or experiments to demonstrate equilibrium in a physical or biological system; select from a variety of modeling techniques the one most appropriate for a particular purpose; explain how criteria and constraints in real-world situations require making tradeoffs; use symbolic equations to summarize how quantities change over time; identify examples of cyclical changes; use orders of magnitude to describe the range of sizes in the observable world; trace examples of evolution in science, mathematics, and technology	design and execute a model or experiment to demonstrate dynamic equilibrium; use modeling techniques to contribute to the solution of a problem; demonstrate use of cost-benefit and risk-benefit analyzes in making decisions; use graphs and equations to depict and analyze patterns of change; monitor cyclical changes and describe them in terms of their cycle length and frequency; use orders of magnitude to describe the range of sizes from subatomic to galactic; illustrate how large changes in scale impact a system's performance; explain the patterns and processes of evolution in mathematics, science, and technology
compare ways in which mathematics, science, and technology affect daily life, earlier generations and people in other parts of the world; describe the values and motivations that lead people to seek new knowledge in mathematics and science and to improve technologies; describe early developments and major milestones in the history of mathematics, science, and technology	describe examples of how advances in mathematics, science, and technology have affected and been affected by social values and people's view of the world; compare data and interpretations of data with those of other students; investigate the mathematical, scientific, and technological background of examples of social issues and describe the variety of opinions on these issues; trace the changing relationships among society and mathematics, science, and technology over time	explain how modern mathematics, science, and technology affect our values and world view and how these affect the search for knowledge and applications of knowledge in these fields; explain why experts sometimes disagree about the interpretations of data and/or about courses of action on social issues related to mathematics, science, or technology

This short-term activity is an example of how intermediate-level students might participate in an activity representing the integrative theme of stewardship of the environment. Here students make connections beyond mathematics, science, and technology to other disciplines such as language arts for listening skills, and social studies for comparison to other eras.

How Many is Enough?

In this activity students use a simple model to illustrate resource depletion and suggest variations to the model which would allow management of population size for a wildlife species.

The intent of this activity is to explore population change through the combined use of a simple model (a game) and a historical story in order to suggest that even apparently plentiful renewable resources (wildlife populations) may become endangered or extinct. The focus is on population/habitat changes brought about by human/wildlife interactions.

Science Concepts:

- **Natural balance may be disturbed in various ways, natural and human:** Students model the manipulation of variables and see the responses in population size.
- **Soil, plants, animals, and water are renewable resources which humans, through overuse, can deplete:** Students discover that attention must be extended beyond individuals and populations to habitat retention if prevention of wildlife depletion is to become a social priority.

Special extensions relating to technology and mathematics:

- **Technology:** Our perception of a natural resource as plentiful or renewable may overlook important factors such as territorial requirements or the time required for a resource to renew itself. Students could research the impact that modern fishing technology has had on the "limitless" resources of the ocean.
- **Mathematics:** Students could graph the data from the game (description follows) and determine the average number of birds caught during each round of play by dividing the initial number of birds by the number of rounds of play required to empty the container.

Conducting the game and the reading:

1. Divide students into groups of four or five (four if you are the group timer for all, five if each group has its own timer). Have students within groups form pairs.
2. Provide each group with a container (paper cup) more than half full of paper clips and a container less than half full of paper clips of a different color. Explain that each paper clip in one container represents an individual of one kind of bird and that all the clips in that container represent a wild bird population (i.e., all are of the same species). Each clip in the other container represents one individual of another population (i.e., a different species) of birds. The containers represent the habitats of the two populations.
3. One pair of students in the group works with one cup and the other pair works with the other cup; both pairs remove clips simultaneously from their own cups. A round takes one minute to complete, with students taking turns removing paper clips from their cup, one at a time, and placing them in a paper bag.
4. At the end of one minute a round ends and play stops. Each pair of students counts how many clips have been removed from the cup, records results, and then compares results with the other pair. The pair that started with less than half a cup returns all the paper clips to the cup. The pair that started with more than half a cup divides the total of removed paper clips in half, returning half to the paper cup and placing the other half in an envelope.

Adapted from *Wildlife and Humanity: Can We Share the Earth?* Albany, NY. Science, Technology and Society Education Project, 1993.

5. Continue rounds until one of the cups is empty. Students should record the number of repetitions required to empty that cup.
6. Following a discussion of results, read the story *Martha* and have students make connections to the paper clip activity.

Students should be able to produce population growth curves, using graph paper. They should also be able to describe the analogies present in the game, coming up with explanations such as the following: population size can be determined by counting the number of paper clips; the removal of an individual from a cup represents the death of that individual; the students who remove the paper clips from the cups represent humans carrying on unlimited hunting, trapping, or some other form of harvesting of the bird population; the paper clips returned to the cup after each round represent offspring born during the year (of particular importance here is that not all organisms have the same reproductive rate; especially endangered by habitat destruction or excessive hunting are certain birds and large mammals that have low reproductive rates); an empty cup represents a habitat that no longer contains one of the populations we are modeling.

We invite activities that integrate themes in mathematics, science, and technology and make connections to other disciplines.

Afterwards, ask probing questions to ascertain how well students comprehend the analogy between changes in the passenger pigeon population size and the manipulations students performed with the paper clips.

Focusing and Directing Questions:

- Did you believe that the larger bird population was more secure (not endangered, safer) than the smaller population as you began the game?
- How would the outcome have changed if each time we had returned less than the original amount to the container that started less than half full? What if we had returned more than the original amount to the container that started less than half full?
- The model we used simplified true situations. What other factors besides the original population size, predation, and the reproductive rate determine the security of an animal population?
- In what ways did our model seem to match the real world well? poorly?
- During the bird game, did it occur to you that the birds might need legal protection in order to survive as a population?
- If you were a settler during the mid-1800s and you depended on hunting for fresh meat, how receptive would you have been to measures protecting what seemed to be a plentiful and renewable resource?
- Are there endangered wild creatures today?
- What measures have humans taken in attempts to help them?
- Are all endangered animals benefited by laws and by wildlife conservation and management efforts?
- What happens to population density if you modify the "reproduction" rate of one or both of the populations?
- What happens to population density if you modify the predatory pressure on one or both of the populations?

Martha

Close your eyes, relax. Get as comfortable as you can. I am going to read you a story. As I read it, I want you to try to imagine the scenes and events.

When European explorers first came to America several hundred years ago, they found large flocks of birds which came to be known as passenger pigeons. There were millions and millions and millions of them. The passenger pigeon was a large and graceful bird. Including its long, tapering tail, it was about 16 inches long. The head and back of the male were a glossy bluish gray, and the breast was red. The head and back of the female were light brown, and the breast was gray. The passenger pigeon had sparkling red eyes—some people described the color as "bright, fiery orange."

The passenger pigeon diet consisted mainly of beechnuts, acorns, berries, and seeds, which were in abundant supply in the forests where the birds nested. They built flimsy, platform-style nests of sticks and twigs and nearly always laid only one egg at a time. Usually more than a hundred passenger pigeons nested in the same tree. Sometimes there were so many nests that limbs would break off and fall to the ground. Many other passenger pigeons nested in trees nearby; in fact, they lived together in such large numbers that nesting areas were huge! A nesting area found in Michigan was 28 miles long and 3 to 4 miles wide.

The nesting areas were so densely populated by the passenger pigeons that their droppings killed ground-level plants and stripped the trees of leaves. One person said that a nesting area looked as if it had been struck by a tornado! Nesting areas were also noisy places. The birds were loud and were reported to sound like a huge army of bullfrogs.

Passenger pigeons flew south in the fall. Known as "blue meteors," the birds could fly a mile a minute. They flew in flocks so enormous that they could block out the light of the noon-day sun. It was said that their wings "roared like thunder."

Passenger pigeons were also very tasty and as a result were avidly hunted. Hunters killed large numbers—one hunter allegedly killed 1200 a day over a week-long period. Some people killed the birds with sticks and stones, while others trapped them with nets placed over trees; in fact, pigeon netting was such a common practice that almost every town was equipped with a net. Pigeons were caught in other ways, too; some people soaked grain in alcohol and used it as bait. The birds would eat the bait and then become immobilized. As they lay helpless on the ground, they were simply gathered up. Sometimes trees were cut down and the nestlings were picked up. Additionally, these daytime-active birds were easily captured at nighttime, when they could be knocked down from their roosts with long poles.

The shooting, netting, and trapping continued for years. Wildlife officials believed that protection of the birds was unnecessary because they were so numerous. However, the United States was growing rapidly. Railroad ties were beginning to crisscross the land. The birds' forest habitat was being cut down for timber and land was being cleared for farming. The birds' food items—beechnuts, acorns, and berries—were becoming scarce. As a result, the flocks of pigeons became smaller and smaller and were scattered farther and farther apart.

Finally, protective laws prohibiting the hunting of passenger pigeons were passed. People thought the birds were safe, but each year fewer and fewer pigeons were seen. The inherited habit of laying only one egg at a time did not allow passenger pigeon populations to replenish themselves very rapidly. On September 23, 1907, the last passenger pigeon in the wild was shot.

But some were kept in zoos, and there was hope that these would survive. However, even in zoos the older birds died faster than the young birds hatched.

Eventually there was only one bird left. Her name was Martha, and she lived in the Cincinnati Zoo. Not much was known of Martha's past. She was probably born from a pair of captured pigeons in Wisconsin. She arrived at the Cincinnati Zoo in 1902. Her age at that time was a mystery, so no one knew for sure how old she was when she died. She might have been as young as 14 or as old as 29.

Martha is now mounted in a display case at the Smithsonian Institution in Washington, DC. The label on the case reads: "Martha, Last of her species, died at 1 p.m., On September 1, 1914, age 29, in the Cincinnati Zoological Gardens."

When you are ready, open your eyes.

STANDARD 8—INTERDISCIPLINARY PROBLEM SOLVING

Students will apply the knowledge and thinking skills of mathematics, science, and technology to address real-life problems and make informed decisions.

Overview

Despite the pervasiveness of technology and the application of mathematical and scientific principles and techniques to the affairs of everyday life, few students are consciously aware of these interactions. One way is to organize content on the basis of its usefulness in solving mathematics, science, and technology-related problems in society. This organizational arrangements lends itself to interdisciplinary project work by students. Classroom activities and project work should provide students experiences that allow them to use knowledge and skills from mathematics, science, and technology to assist in personal and societal problem solving, decision making, and action taking. Interdisciplinary problems relating to areas of study such as health care, industry, the environment, parenting, consumer choices, adaptations for people with disabilities, and national defense concerns are potential contexts for student activities.

The key competency related to the interdisciplinary problem-solving standard is:

- Applying integrated knowledge to solve interdisciplinary problems and to make informed decisions

At the elementary level, students

participate in a 2-4 week integrative project that applies elementary level mathematics and science skills, knowledges, and attitudes to the solution of a technological design problem involving a familiar subject relating to the home or school context

The project might include:

Planning
(e.g., consulting with classmates, parents and friends; visiting libraries; reviewing magazines)

At the intermediate level, students

participate in a 4-6 week integrative project that applies middle-level mathematics and science skills, knowledges, and attitudes to the solution of a technological design problem involving a subject of general social interest related to a home, school, or community context

The project might include:

Planning
(e.g., reviewing past attempts at solving similar problems; consulting specialists and community members)

At the commencement level, students

participate in a 6-10 week integrative project that applies high school level mathematics and science skills, knowledges, and attitudes to the solution of a technological design problem involving a community, national, or global issue

The project might include:

Planning
(e.g., reviewing research in the specific field; consulting with a range of experts by phone or through written correspondence; using library resources and computer data bases)

Graphing and Statistical Analysis
(e.g., collecting, displaying, and drawing conclusions from data relating to performances and results, student preferences, and anthropometrics)

Measurement, Computation, Prediction, Analysis of Probability
(e.g,, using simple measuring tools to make approximate measurements; using four-function calculators to compute costs, including: costs per user; determining physical dimensions of objects, and materials; predicting how changes in procedures would affect results; and analyzing the probability of occurrences of errors and variations)

Sketching and Illustrating
(e.g., freehand sketching, illustration and coloring)

Experimenting/Modeling With Simple Construction Tools and Concrete Materials
(e.g., to produce objects and/or dioramas from familiar resistant and malleable materials)

Working in Groups and As Individuals
(e.g., working in brainstorming groups, laboratory partnerships, cooperative learning groups, project teams, quality circle groups; as individuals, doing research, constructing components or models, and thinking about procedures and results)

Planned Dialogue About the Project
(e.g., planning, discussing procedures, making ideas and thoughts explicit through talking about them, giving and receiving critical feedback)

Graphing and Statistical Analysis
(e.g., systematically collecting, organizing, and describing data; constructing, reading, and interpreting tables, charts, and graphs relating to performance data or anthropometric data gleaned from investigations about the "average" student in their school or the "average" person in their community; using frequency distributions to display preferences or occurrences)

Measurement, Computation, Predication, Analysis of Probability
(e.g., selecting and using appropriate units and tools to measure to the degree of accuracy required; using concepts of rates and other derived and indirect measurements; using simple formulas to compute answers; predicting how changing variables might change responses; analyzing the results of experiments or simulations to determine the likelihood of an event)

Sketching, Drawing, Illustrating
(e.g., using drawing tools including simple CAD programs and paint programs; generating two- and three-view drawings; using rendering techniques)

Experimenting/Modeling With Simple Construction Tools and Concrete Materials
(e.g., using multifunction calculators to compute whole number fractional and decimal quantities; using computer-based modeling software; constructing objects and/or dioramas, using a combination of resistant and malleable materials, and material conversion processes including cutting, forming, combining, and conditioning)

Working in Groups and As Individuals
(e.g., students practicing face-to-face interaction, interdependence, and giving and receiving information; each individual being accountable for learning the material; and analyzing how well members of the group are using social skills)

Planned Dialogue About the Project
(e.g., talking about stages in project development, identifying and talking about thinking skills such as, information gathering, organizing, analyzing, and evaluating; discussing, evaluating results, and suggesting improvements)

Graphing and Statistical Analysis
(e.g., constructing and drawing inferences from charts, tables, and graphs that summarize data from real-world situations; using sampling techniques; applying measures of central tendency)

Measurement, Computation, Prediction, Analysis of Probability
(e.g., using computer-based probes and sensors to make measurements of temperature, sound level, current, etc.; using instruments, lab ware, meters and gauges; using curve fitting to predict from data; determining likelihood that results could have occurred by chance)

Sketching, Drawing, Illustrating
(e.g., using computer-generated and hand-drawn diagrams, sketches, and drawings; rendering, shading, and texturing illustrations)

Experimenting/Modeling With Tools and Materials
(e.g., designing a controlled experiment having multiple variables which relates to a real-world situation; using computer modeling and simulation techniques; constructing models of systems, products, or environments, using a wide range of materials and mechanical and electronic tools)

Working in Groups and As Individuals
(e.g., using cooperative learning techniques, including a focus on contact management skills, and development of trust; providing for individual accountability)

Planned Dialogue About the Project
(e.g., talking with classmates, other interested parties, members of school/local community about the project, to receive feedback)

Presentation of Finished Project
(e.g., groups and individuals taking responsibility for a review of the planning, designing, implementation, and testing cycle; and for graphic and oral presentation of results)

Documentation of Work
(e.g., students maintain an MST portfolio, including sketches, drawings, graphs, charts, pictures, and written explanations of problem statements, hypotheses, investigations undertaken, letters, ideas and rejected ideas, investigations and procedures, design solution possibilities, developed design solutions, results, and suggestions for improvement)

Project Example
An elementary level integrative activity might address the issue of recycling solid waste in the context of the school. Students would reach consensus on the need for recycling and choose a material to recycle. If paper is chosen, students might determine which materials can and should be recycled; measure the amount (weight, volume) of recycled paper in their school during a one-week time period; calculate the cost of such paper; chart usage of paper per person per week; compare and contrast the established usage to published per person usage; classify paper into categories (types, sizes, colors).
Students would then, using simple mixers, wire screens, and lint, leaves, rags, etc., recycle paper into a useable sheet. They would add bleaching and color to the mix; and compare various class-produced papers relative to appearance, absorption, writing quality, and strength. They would use their paper and their paper recycling experience to write a poem or story about recycling

Presentation of Finished Project
(e.g., groups presenting results orally and in writing, using computer-generated charts and graphs)

Documentation of Work
(e.g., students develop an MST portfolio including sketches, drawings, graphs, charts, pictures, and written explanations of problem questions, hypotheses, investigations undertaken, ideas and rejected ideas, experimental procedures, the design of solution possibilities, developed design solutions, results, suggestions for improvement or new predictions or hypotheses)

Project Example
An intermediate level integrative activity might address auto safety issues. Students would investigate the scope of the problem, graph accidents and highway fatalities over time, study trends, analyze the impact of the 55 mph speed limit; investigate correlations between drunk driving and fatalities, and accident rate and sex/age; and suggest local actions that could ameliorate the situation.
Students might design and construct a model vehicle which carries a raw egg as a passenger, rolls down a ramp, and crashes into a barrier. They would design restraint systems to protect the egg, and design the vehicle with crush zones to absorb impact. They would analyze forces, and compute acceleration using F=ma calculations

Presentation of Finished Project
(e.g., oral, graphic, and written presentations to classmates and community groups; articles to local newspapers; presentations to local community leaders to lobby for support of the project; use of multimedia presentation techniques)

Documentation of Work
(e.g., students produce a MST portfolio, including sketches, drawings, graphs, charts, pictures, and written explanations of problem statements, hypotheses, investigations undertaken, letters, ideas and rejected ideas, experiments and procedures, design solution possibilities, developed design solutions, results, and suggestions for improvement, original photographs taken during presentations, publicity received, and such items as letters of support)

Project Example
A commencement level integrative activity might relate to the issue of emergency preparedness. Students would share with each other memories of personal experiences with natural and human-caused emergencies and school emergency drills. The teacher could challenge students to generate a disaster scenario, and research the characteristics and consequences of previous incidences of the causative agent.
Students might design a portable shelter for use by persons stranded on a mountaintop after a plane crash. The shelter would be heated by the body heat of five survivors, to a life sustaining temperature, given an outside temperature of 20 degrees F. The emergency preparedness shelter would theoretically be dropped to the survivors by an aircraft and must be capable of withstanding the impact of the drop. Scale models, or full-sized shelters, could be designed and constructed, based on engineering design criteria including wind load, snow load, and insulating properties of materials. Heat flow calculations could be done to determine how the body heat of the individuals could be used to heat the shelter. Pictorial assembly instruction would be provided, so that speakers of any language could quickly install the structure on site. Students would determine the kinds of data to be collected, for example snowfall during certain months, average wind velocity, R value of insulating materials, etc. Students would develop ways to standardize and display collected data and analyze and communicate results.

Students will develop habits of mind and social and career-related skills in mathematics, science, and technology education classes that will enable them to work productively with others, achieve success in a postsecondary school setting, enter the workplace prepared to achieve success in different jobs, and possess skills necessary for lifelong learning and continuing advancement.

Overview

Beyond the discipline-specific knowledge and skills described in earlier standards, there are additional understandings, skills, and attitudes that specifically prepare students for postsecondary academic and vocational success and for lifelong learning. Standard 9 shows why acquiring skills and knowledge is valuable and time well spent by individuals or groups. Teachers of mathematics, science, and technology share responsibility for providing students with experiences that foster an understanding of why an education is worth having.

There exist in mathematics, science, and technology certain values and attitudes, or habits of mind, that add significantly to a person's understanding and appreciation of the world and to effective action as a citizen and worker. Such values and attitudes are not exclusive to the field of technology, although that field has traditionally given these habits of mind great emphasis and refinement.

Curiosity and open-mindedness promote discovery and intellectual growth, illustrating the reality and value of conflicting ideas in society. Without such values, humans often fall victim to their limited vision. Accordingly, they may fail to determine optimal solutions to problems or may make less than wise decisions.

Those successfully engaged in mathematics, science, or technology are persistent and able to marshal evidence effectively, rather than simply to make assertions. This skill clearly transfers to broader societal and vocational challenges in which thorough and sustained application of knowledge and skills tends to lead to greater accomplishment and success.

Demand for verification and an informed skepticism, when balanced with an openness to new ideas and approaches, direct an individual to seek evidence not only for discipline-bound assertions but also for more general claims made in society and the workplace. In an era when information can easily be manipulated and distorted to support the goals of private enterprise and special interest groups, the tendency to examine arguments critically and consider alternatives enhances the quality of decision making. In this regard, the respect for and use of logic as a means of drawing and judging inferences from such information provides a powerful vehicle to ascertain the reliability and validity of the associated arguments.

Even if assertions appear to have sufficient evidence and are logically consistent, they may be based upon faulty premises and assumptions. Mathematicians, scientists, and technologists habitually consider their premises; such a habit, when consistently applied to more general lines of reasoning, can reveal fallacies in what initially appear as tightly constructed thought patterns.

Specialists whose work holds social import typically consider the consequences of their research upon human beings. Specialists may also engage in a careful cost-benefit analysis. This value, if internalized by students, can help them to make responsible and ethical decisions in all aspects of their lives.

Much of human endeavor in settings of all kinds is carried out by collaborative groups rather than individuals working in isolation. Students must learn to value and employ one another's unique qualities and contributions, as well as learning how to advance cooperative ventures for the common good. Since change is ever increasing in quantity and rate, students must also come to appreciate the positive value of change in their lives.

The key concepts and competencies related to the future-preparedness standard are:

- Habits of mind, including: being curious, open-minded, and persistent; demanding verification; using sound reasoning; and considering consequences
- Interpersonal skills
- Career-related skills

At the elementary level, students

Habits of mind
frequently ask questions and take initiative in trying to find answers in the areas of mathematics, science, and technology; listen to and consider the ideas of others in solving problems relating to mathematics, science, and technology; stay on task until completion; ask for reasons to believe in ideas and for using accepted procedures in mathematics, science, and technology; discriminate between fact and fiction; describe ways that the use of mathematics, science, and technology in daily living can help and harm people

At the intermediate level, students

Habits of mind
seek to learn more about areas of interest in mathematics, science, and technology; are willing to change ideas when new or additional evidence is available; exhibit self-direction and motivation in the completion of tasks; look for evidence and/or proof to support a solution to a problem in science, mathematics, or technology; recognize and point out the premises in the arguments of others within the context of mathematics, science, and technology; examine personal understandings that may affect the approaches taken and the conclusions drawn in problem solving; use mathematics, science, and/or technology to develop a list of alternative choices that could be made in addressing a personal or societal issue, giving reasons for each choice

At the commencement level, students

Habits of mind
explore problems of interest to individuals and society, using concepts and skills in mathematics, science, and technology to develop potential solutions; test assumptions about mathematics, science, and technology and evaluate ideas which differ from their own; complete complex tasks independently; apply appropriate logical systems to judge the consistency and validity of inferences; analyze the assumptions in mathematics, science, and/or technology upon which particular conclusions or decisions are based; notice and criticize arguments in which fact and opinion are intermingled, premises are not made explicit, and analogies are not apt; in decision making, examine for each alternative choice its consequences, the people affected and how affected, and the values related to that choice, eventually deciding upon and defending one of the choices examined

At the elementary level, students

Interpersonal skills
participate in small group projects in which individuals have defined roles; participate in heterogeneous groups, and in structured group tasks, (e.g., brainstorming, debating) in mathematics, science, and technology education classes

Career-related skills
describe how certain careers in mathematics, science, and technology require education beyond high school; describe careers of family members and friends which depend upon knowledge and skills in mathematics, science, and technology

At the intermediate level, students

Interpersonal skills
listen actively, disagree agreeably, check for consensus, and reflect on group process during group activities; assume leadership responsibilities within structured group activities in mathematics, science, and technology education classes (e.g., Youth Leadership clubs, Math Counts, Science Olympiad, JETS); display encouragement, sensitivity, and empathy in dealing with classmates

Career-related skills
describe how work, job opportunities, and careers are in constant change because of the evolution of mathematics, science, and technology; develop a list of careers in mathematics, science, or technology of personal interest with positive and negative attributes of each indicated; identify an appropriate high school program oriented toward a career in mathematics, science, or technology

At the commencement level, students

Interpersonal skills
engage in face-to-face interaction, demonstrate accountability, refine interpersonal and small group skills (e.g., communications, leadership, decision making, and conflict management), and analyze group process within the context of group activities; evaluate ability to contribute as a member of a group; assume a position of responsibility

Career-related skills
research and identify careers in mathematics, science, and technology in which the number of jobs is projected to grow; explain how the global economy affects the vitality of industries and the demand for jobs; develop and describe a postsecondary educational program appropriate to the requirements for a career in mathematics, science, or technology

CHAPTER IV: CONNECTING CURRICULUM, INSTRUCTION, AND ASSESSMENT

Creating a Seamless Web

"Good assessment is just good curriculum with a scoring guide," claims a leading developer of performance assessments.[2] If learning experiences are to be challenging, coherent, and aimed at developing the full range of students' capabilities, then curriculum, instruction, and assessment must also be interrelated and interconnected. They must be seen as mutually dependent and jointly aimed at enriching the continual growth and learning of each individual student. Schools must view learning as an integrated activity, connecting ideas and understandings within and across disciplines and between school and non-school performance settings. Assessment must be embedded in the teaching and learning process, rather than "delivered" out of context and, frequently, out of content, at discrete testing moments throughout a student's career. Assessment must be dynamic, rich with information about student potentials as well as progress, and motivating to students, teachers, and schools as it illuminates compelling goals along with means for reaching them.

The Council's recommendations for a system of State and local assessment are based on the principles, articulated in its Interim Report, that assessments of student performance should:

- be as authentic as possible, representing real-world tasks and situations requiring higher-order thinking, applications of knowledge, and complex, integrated performances;

- provide multiple ways for students to demonstrate their knowledge, skill, and understanding, including written and oral examinations, performance tasks, projects, portfolios, and structured observations by teachers;

- enable teachers to assess student growth in a cumulative, longitudinal fashion, using many kinds of evidence;

- be measures of actual performance that can be easily expressed, used, and understood by students, parents, teachers, and the public;

- communicate expectations and support student motivation, self-assessment, and continual growth;

[2] Joan Boykoff Baron. "Assessment Program in Connecticut and Performance Assessment Collaboratives in Education." Paper presented to the New York State Curriculum and Assessment Council, June 14, 1993.

- use criteria that are public, open, and clearly articulated so that they can guide teaching and learning;

- inform instruction and encourage reflective practice;

- be valid and accurate for identifying students' strengths, abilities, and progress, opening up possibilities for encouraging further growth rather than precluding access to future advanced instruction.[3]

Complex understanding is the hallmark of meaningful learning; the mere presence of bits of information does not indicate that in-depth learning has occurred. Therefore, assessments must be used that will determine whether or not students have developed complexity of understanding. Assessments showing that students have simply memorized information do little to enrich the educational process.

Specifically, assessments should gauge students' capacity to use concepts, principles, and theories to construct new ideas and to solve real-world problems. Consequently, assessment techniques need to be multifaceted, closely allied with instruction, and formative as well as summative.

Standards cannot be adequately assessed by a single instance of evaluation since they reflect habitual performance over time. Furthermore, since standards are open-ended, they can only be partially assessed by objective testing. Therefore, it is necessary to specify performance criteria and to assess over a period of time, using different assessment strategies. These include:

- teacher observations

- portfolio documentation of learning

- self-assessment reports

- exhibitions and demonstrations

- interviews

- essays

- critiques of students' work by outside experts.

Because we assume that achievement of each of the standards is essential to adult competency, we need to:

- adopt flexible time frames for learning

- assess in terms of levels of achievement and stages of development

- reject the notion of the success-or-failure dichotomy.

Exemplars of Performance

Performances can consist of short-term or long-term student activities, and ideally they would be thematic and integrative, involving the students in active learning. Performances should allow students to authentically demonstrate their capacity to satisfy various performance indicators. These same

[3] *Learning-Centered Curriculum and Assessment for New York State.* Report of the New York State Curriculum and Assessment Council to the Commissioner of Education and the Board of Regents. November 1993, pp. 15-16.

performances will enable teachers to assess how well students are managing the active learning process. Assessment embedded in instruction makes the transition from instruction to assessment seamless, and uses the instructional strategy itself as the assessment tool.

Exemplars of performance are descriptions of performance at the elementary, intermediate, and commencement levels, and they are often built around real-world problems or issues that have relevance to the lives of students. Exemplars of performance provide a setting, reference a standard or some aspect of a standard (area of study, concept, competency), and when accompanied by a scoring rubric, provide examples of student responses at various levels (e.g., distinction, proficient, competent). Descriptions or examples of student work can also be part of the exemplar, and they are included to help teachers and others evaluate levels of performance.

We invite examples of mathematics, science, and technology performances used in schools.

Four exemplars follow: the first three demonstrate the integration of the three disciplines. All four exemplars show linkages to the mathematics, science, and technology standards of this framework and to the performance indicators. The fourth exemplar, Comparing Grizzly Bears and Black Bears, does not contain a technology component, but it is included because it has a scoring guide. The exemplars are not intended as recipes for teaching from a curriculum framework. They are included in the framework to help readers envision how teaching and learning on the basis of standards and the development of authentic tasks might occur in their own schools. We invite teachers and curriculum coordinators to contribute examples of exemplars that they are using successfully in their classrooms.

PAPER AIRPLANE TESTING

Level

Elementary Short-term Activity (3-4 days)

Problem

Students work individually and cooperatively to design, construct, test, and improve the performance of paper airplanes. They agree upon testing procedures and select an official class design for their airplanes. They test separately the effects on performance of varying the kind of paper used for construction and the scale of the constructed airplane.

Classroom Activity

1. Give each student a piece of paper (all pieces of the paper must be the same size and kind) and challenge each to physically change the paper to produce the best shape for keeping the paper floating in air as long as possible (or, alternatively, traveling the greatest distance through the air). Clarify the challenge by providing the following information:

- you have five minutes to complete your design.
- you are not allowed to add or take away any material (work with only the piece of paper)

2. At the end of five minutes, allow each student to test the float time for his or her design and then divide the class into cooperative learning groups of 3-4 to share what they have learned from the experience. Have each group agree upon, design, construct, and test a new airplane. Once again, the mission is to have the airplane remain afloat for as long as possible. Provide students measuring devices so they can keep track of the dimensions of the various designs they test, and allow them to use a hair dryer or other item that can provide air motion to determine how various components of their design, such as wing shape, can affect the airplane's performance.

3. Have a committee of students representing the various cooperative groups meet and agree upon conditions for testing the group-made airplanes and for selecting the best design from among the airplanes. The committee should generate, discuss, and research the answers to questions such as the following:

- Where would be the best place to carry out the flight tests?
- How can we ensure that each plane is launched in as uniform a way as possible?
- What do we need to do to make the tests as fair as possible?
- How many test flight trials per plane are needed to identify which airplane consistently stays afloat the longest?

4. Conduct the formal tests of the various airplanes and declare the design of the winning airplane the official class design.

5. Have each cooperative group construct a new airplane (still using the same kind and size of paper) according to the official class design. Have half the groups compare their new airplane to similar airplanes they construct from *different kinds* of paper. (What is the effect of varying the composition of the material used to make the airplane?) Have the other half of the cooperative learning groups compare their new airplane to similar planes they construct using *different scales.* (What is the effect on performance of changing scale for the same design of airplane?) In this case give the groups pieces of the same kind of paper twice the size of the original and half the size of the original. After this new round of constructing and testing, match cooperative groups who worked on different problems with each other for debriefing purposes.

6. If students are motivated to do so, provide them opportunities to improve the performance of their airplanes by incorporating other materials into the design. Students might benefit from library research and interviews with persons in the airline industry.

Assessment Opportunities: Standards/Performance Indicators Addressed:

Standard 1—Analysis, Inquiry, and Design

Performance Indicators: Students model problem situations, using concrete objects; form testable ideas based on some prior knowledge; make accurate observations of objects and events; select and use standard measuring devices to collect data on such physical quantities as length; interpret from organized observations and measurements simple patterns or relationships among variables; hone ideas through reasoning and discussion with others and through research techniques; suggest ways in which something can be changed or improved; plan and build a model of a solution; draw conclusions and make further predictions

Standard 2—Systems

Performance Indicators: Students assemble and operate simple technological systems; identify interactions among system components.

Standard 3—Information Resources

Performance Indicators: Students access information from a wide variety of community resources, such as experts or other knowledgeable persons.

Standard 4—Science

Performance Indicators: Students observe and describe the properties of materials; observe and describe physical changes; observe and describe the effects of common forces such as gravity on objects; observe and describe objects in motion.

Standard 5—Technology

Performance Indicators: Students select and use simple tools; use technological processes to transport airplanes; model solutions to design problems; recognize and describe how various material resources have different properties and understand that some are better than others for a specific use.

Standard 6—Mathematics

Performance Indicators: Students investigate and predict the results of combining, subdividing, and changing shapes; use concrete models to model correspondence; relate geometric concepts to everyday situations; select appropriate standard and nonstandard measurement tools in a measurement activity; model probability concepts, using concrete objects; collect, organize, represent, and describe data; use patterns and relationships to analyze mathematical situations; make application of numbers and numeration concepts; justify answers and solution processes.

Standard 7—Connecting Themes

Performance Indicators: Students give examples of how people use mathematics, science, and technology to solve problems; distinguish between absolute and relative scale.

HOW CAN WE PREPARE THIS WATER FOR EVERYDAY USE?

Level
Intermediate

Approximate Time in Days
10 days

Problem:
Students, after studying the properties of water, are challenged to pool their prior knowledge and work together to design and implement a simple plan to prepare a local surface water sample for everyday human use (washing clothes, brushing teeth, wiping the table, filling a goldfish bowl or birdbath), except for drinking by humans. Evaluation is embedded in the activity to the extent that the teacher assesses the design of the plans as well as the various devices constructed to prepare water for everyday use.

Classroom Activity
1. Show the class a large aquarium or transparent bowl filled with murky water taken from a pond or stream.

2. Stir the water, and then provide each cooperative group of three to four students with a sample taken from the container.

3. Ask students to observe their samples individually and record what they see in their journals, both as a list and as a labeled drawing.

- What can you tell me about your sample of water?

- What substances are in the water that you can directly observe, using your senses other than taste?

4. Have students describe what they observe in the sample of water. Explore with them the difference between an "observation" and an "inference." Generate a list of their actual observations of what is in the water. Make sure that each item on the list can be backed up with a specific observation that the group can agree upon.

- Is everything in the water necessarily bad for us?

- How comfortable are you with the idea that all the information we need about what is in the water can be gathered with our unaided senses?

- What technological devices could be used to aid our senses?

5. Have students ask questions and state concerns, if any, about the quality of the water beyond what they can observe.

- What else concerns you about the water?

Adapted from *Water: How Can We Keep It Fit For Life?* Albany, NY. Science, Technology and Society Education Project, 1994.

• What inferences can you make about what might be in the water?

6. Tell the students that you are interested in hearing what they already know about treating water to make it ready for human use. Give the groups time to discuss the topic of water purification and to list ways to change water that is not adequate for everyday use. Have a reporter from each group describe one way the water can be improved for use (each group reporter should describe a different action), and list the various ways on a large easel pad or transparency.

7. Tell the students they are now responsible for designing and carrying out a plan to make their samples of water ready for everyday use. Each plan for treating water samples should be based on what is known to be in the water and what is inferred to be in the water.

8. Have group reporters describe each group's plan of action and "wish list" of materials for purifying the water sample. Some plans may be feasible, while others may be only partially acceptable (to you) for safety, economic, or other reasons. Help the groups make revisions as necessary, and have them carry out their plans or parts of their plans. Later, have students make quantitative measurements to compare preparation techniques selected by various groups. Comparisons might be made for such factors as the amount of time needed to produce a given quantity of water, or of the amount of water prepared compared to the total amount of water processed.

• Now that you've treated your water, are you confident that it is ready for everyday use except for drinking by humans?

• Should all water be "purified"? How do other organisms use the water?

• Is clear, colorless, odorless water "pollution free" and safe to drink? Should humans drink the water you treated? Why or why not?

• Are you satisfied that all has been done that could be done to prepare the water for everyday use?

• Are you sure that you now have all the information you need to prepare water for everyday use?

• What other information do you need?

• How can you get that information?

Supplementary Information

Students who concentrate on the visual components of the dirty water will come up with treatment plans such as: straining the water through a sieve; filtering it through a coffee filter; letting the sample sit overnight to settle the solids to the bottom; or draining the liquid through charcoal and/or sand. Some students might recall the phase change property of water and convert the liquid to water vapor by evaporating it in a closed container and then collecting the condensation. Some students may recall the special solvent capacity of water, but they are unlikely to be able to suggest specific chemicals that will remove dissolved particles from solution.

Assessment Opportunities: Standards/Performance Indicators Addressed:

Standard 1—Analysis, Inquiry, and Design

Performance Indicators: Students suggest testable ideas; defer judgment until a number of ideas have been generated; evaluate ideas; express and defend opinions; hone ideas through feedback from formal oral proposals, group discussion, and investigations; develop plans; accurately construct a model of the solution; formulate quantitative relationships among variables.

Standard 2—Systems

Performance Indicators: Students assemble, operate and explain the operation of technological systems which produce outputs including products; identify interactions among system components.

Standard 4—Science

Performance Indicators: Students observe and describe complex properties of materials.

Standard 5—Technology

Performance Indicators: Students describe how the choice of materials depends upon their properties and characteristics, and how they interact with other materials; identify and describe a biotechnical process used in designing a range of systems such as water purification.

Standard 6—Mathematics

Performance Indicators: Students develop the concept of ratio; compute quantities such as volume using standard units of measure.

Standard 9—Preparation for the Future

Performance Indicators: Students listen actively, disagree agreeably, check for consensus, and reflect on group process during group activities; recognize and point out the premises in the arguments of others within the context of mathematics, science, and technology; are willing to change ideas when new or additional evidence is available.

PRODUCING HEALTH CARE PRODUCTS

Level:
Commencement

Approximate Time in Days
20 days

Activity Context
Many people desire health care products for personal hygiene and to enhance appearances. These products include cosmetics, skin creams, perfumes, soaps, deodorants, and lotions. Entrepreneurs profit from the demand for these products by designing, manufacturing, packaging, and marketing them in attractive and appealing ways.

Challenge to Students
Design and produce a product from one of the above categories and test market it, involving other students in the school. Design a label and package for the manufactured product.

Resources Needed
Ounce and gram scales
Measuring and storage containers
Computer hardware and software
Safety equipment such as rubber gloves and goggles
Graphic arts supplies
Mechanical drawing or CAD equipment
Chemicals to manufacture soaps, lotions, deodorants, creams, or perfumes

Procedure

1. Introduce the health care product design problem. With student input, compile a list of possible products to be produced.

2. Show videotaped commercials for hand soaps, hand lotions, deodorants, or other products. Focus students' attention on package design. Ask students to bring in sample products for analysis of container and label design.

3. Divide students into groups to test and compare sample products and test manufacturers' claims. Compile and analyze product data about such things as texture, smell, and effectiveness.

4. Ask students to recommend and choose software programs which could be used for data collection and analysis, and have them enter data on products tested.

5. Have each group choose a product to produce. Determine ingredients needed. Have students batch ingredients based on design specifications, and discuss how varying formulas will adversely or positively affect the

Adapted from *Introduction to Technology*. Albany, NY. New York State Education Department, 1987, pp. 181-192.

character of the product. Review the function of each ingredient within the mixture. Encourage students to suggest alternative resources and discuss tradeoffs including cost and safety.

6. Develop a test for the final product and perform the test.

7. Discuss safe handling, storage, and processing of materials.

8. Introduce a marketing phase, including design of label, package, and advertising.

Hints to Teachers

Teachers might encourage students to do market research on prototypical products before entering into a production phase. Certain products might involve chemicals that are harmful and discretion must be exercised. In addition to skin care products, the activity might be varied to include the design and manufacture of other chemical products such as fabric flame resistance additives, window cleaning sprays, and glass scratch removers. Connections to social studies might include an explanation about how industrial expansion in the early 20th century stimulated competition among manufacturers. Advertising became a big business in the United States as producers sought ways of enticing consumers to purchase their products. In today's highly competitive society, billions of dollars are spent each year for advertising and marketing.

Assessment Opportunities: Standards/Performance Indicators Addressed:

Standard 1—Analysis, Inquiry, and Design

Performance Indicators: Students apply algebraic concepts to the solution of problems; suggest testable ideas, formulate hypotheses; coordinate a full investigation formulating questions, planning experiments, conducting systematic observation, interpreting and analyzing data, validating and communicating results, and formulating revised hypotheses; initiate and carry out a thorough investigation of an unfamiliar situation; identify needs and opportunities for solution by technological means; generate a number of creative solutions.

Standard 2—Systems

Performance Indicators: Students identify desirable, undesirable, expected, and unexpected outputs resulting from a technological system; in an investigation of a complex system, vary the input and monitor the effect upon the output; using the universal systems model, diagram a system involving multiple subsystems and feedback loops.

Standard 3—Information Resources

Performance Indicators: Students select appropriate software and hardware to collect, sort, analyze, and retrieve information over time.

Standard 4—Science

Performance Indicators: Students explain the properties of materials in terms of the arrangement and properties of the atoms of which they are composed; describe the organization of the human body into subsystems and describe how the body maintains a dynamic equilibrium; explain why vitamins and minerals are necessary to maintain health.

Standard 5—Technology

Performance Indicators: Students describe how technological developments have been influenced by the culture of a society; design a material testing system to test for specific characteristics; explain how manufacturing processes have been changed by improved tools and techniques.

Standard 6—Mathematics

Performance Indicators: Students calculate with the set of real numbers, using a variety of computation techniques; select and use the appropriate method for computing; use estimation techniques to approximate the solution to a problem; design and conduct statistical studies, interpreting and communicating findings; draw inferences from charts, tables, and graphs that summarize data; use instruments and procedures to make indirect measurements.

Standard 7—Connecting Themes

Performance Indicators: Students explain how modern mathematics, science, and technology affect our values and our world view and how these affect the search for knowledge and applications of knowledge in these fields.

Standard 8—Interdisciplinary Problem Solving

Performance Indicators: Students participate in an integrative project that includes planning, graphing, statistical analysis, measurement, analysis of probability, sketching, drawing, modeling with tools and materials, working with groups and as individuals, planned dialogue about the project, presentation of finished project, and documentation of work.

Standard 9—Preparation for the future

Performance Indicators: Students analyze the assumptions in mathematics, science, and/or technology upon which particular conclusions are based; notice and criticize arguments in which fact and opinion are intermingled; refine interpersonal and small group skills; research and identify careers in mathematics, science, and technology.

COMPARING GRIZZLY BEARS AND BLACK BEARS

- Use a real-world context for data.
- Organize unordered data in a meaningful way.
- Compare data sets.

This exemplar of performance contains a scoring guide.

Level:
Intermediate

Suggested time allotment
One class period

Student social organization
Students working alone or in pairs

Task
Assumed background: This item assumes that children have had extensive experience with analyzing sets of data and especially with drawing the type of graph sometimes called a line plot. Students should be accustomed to deciding what kinds of analytic approaches to take. That is, their background should go beyond creating graphs and computing averages to include making decisions about what kinds of computations or visual representations are appropriate in a given situation.

Presenting the task: The teacher should provide a short introduction to the subject matter of the assessment task—two kinds of bears that live in the Rocky Mountains of Montana. Rangers and biologists sometimes collect data on samples of bears. The student's task is to analyze two lists of data pertaining to individual grizzly bears and black bears.

As always, pencils, rulers, graph paper, calculators, etc. should be available.

Assessment Opportunities: Standards/Performance Indicators Addressed:

Standard 1—Analysis, Inquiry, and Design
Performance Indicators: Students apply mathematical knowledge to solve real-world problems and problems that arise from the investigation of mathematical ideas, modeling these problems using representations such as pictures, charts, and tables; generate testable ideas and quantitative relationships among a number of variables.

Standard 4—Science
Performance Indicators: Students describe representatives of the five kingdoms and of the major animal phyla.

Standard 6—Mathematics
Performance Indicators: Students systematically organize, describe, and interpret data, including grouped data; graph linear relationships; use measures of central tendencies to analyze data; apply reasoning processes.

Student assessment activity: See the following pages.

Name ____________________ Date ____________________

The data below give the weights of certain grizzly bears and black bears living in the Rocky Mountains in Montana.

Grizzly Bears			Black Bears		
Bob	Male	220 lbs.	Blackberry	Female	230 lbs.
Rocky	Male	170 lbs.	Greta	Female	150 lbs.
Sue	Female	210 lbs.	Freddie	Male	140 lbs.
Linda	Female	330 lbs.	Harry	Male	230 lbs.
Wilma	Female	190 lbs.	Ken	Male	170 lbs.
Ed	Male	180 lbs.	Hilda	Female	220 lbs.
Glenda	Female	290 lbs.	Grumpy	Male	160 lbs.
Bill	Male	230 lbs.	Blackfoot	Female	150 lbs.
			Marcy	Female	170 lbs.
			Grempod	Male	200 lbs.

1. Organize these data in a way that would help you find which kind of bear is heavier—grizzly bears or black bears. (You can use another piece of paper to do this. Please be sure to put your name on it!)

2. Write down three things that you can tell about the weights of the bears. (You may want to use your answer from question 1 to help you.)

3. Based on these data, how much heavier is a typical bear of one kind than a typical bear of the other kind? ____________

How did you figure out your answer?

Rationale for the mathematics education community

This task requires students to analyze a fairly complex set of measurements obtained from a "real-world" context that is appealing to children of this age group. Rather than simply reading individual values on a graph or from a table, they must view the data set as a whole. More specifically, the problem reveals students' ability to create a representation that shows these data on a reasonable scale in a way that allows comparison of the two groups. (Some students may also find ways to show males and females within each group, thereby coping with one numerical and two categorical variables.)

A second reason for including the task in this collection is that it pushes the curriculum to include work in data analysis, specifically:

- organizing unordered data in a representation that reveals the overall shape and characteristics of the data set;
- describing data sets;
- summarizing data in a way that enables one to compare two data sets.

As with the other tasks in the collection, it requires students to communicate their thinking verbally and graphically.

Task design considerations: Note that there are not the same number of bears of each type, which forces the student to consider more than just the total weights. In fact, the data have been adjusted so that the sums of the weights are the same. This will serve as a subtle hint to the child who adds the two columns of figures and is tempted to stop at that point.

The heaviest bear in the entire set is a grizzly, which is the heavier kind of bear. When looking at student responses, one must be careful to distinguish reasoning that relies on the difference between the central values of the weights from reasoning that simply cites the heaviest bear.

Even though many of the difficulties associated with performing computations on data have been obviated by the advent of inexpensive hand-held calculators, finding suitable "real-world" data is still tricky. Of course, children should have many opportunities to collect their own data, but occasionally one will have to create plausible data from scratch. (Actually, zookeepers and forest rangers do not often weigh adult bears because of the danger involved.) The data in this task come partly from the University of Montana's Office of Grizzly Bear Recovery, supplemented by additional reasonable weights.

Variants and extensions: Other kinds of questions can be asked about the data that are provided here. For example, "What can you say about the weights of male and female bears?" A deeper kind of question deals with age: "Do you think that all these bears are the same age? Explain why you think so."

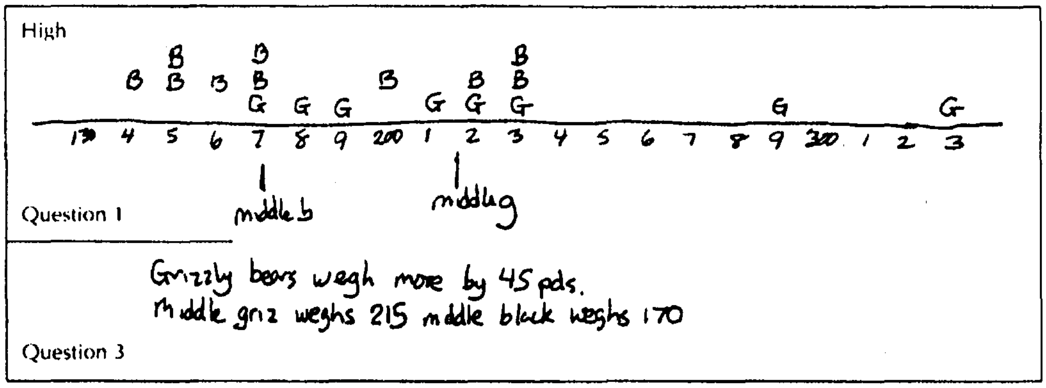
Going beyond this set of data on bears, there are innumerable sources that can be used in creating data-analysis tasks—animal sizes, building heights, river lengths, and so forth. One must be careful, however, to be sure that whatever the objects are, they are equally familiar (or unfamiliar) to the students who are being assessed.

The teacher should be encouraged to follow up the assessment task with appropriate activities. In this case, children might organize oral or written reports to the class, using information about other kinds of bears, perhaps illustrated with graphic displays, posters, etc.

Protorubric

This protorubric is based on the assumption that the child will interpret the task as one calling for the creation of some sort of graph.

Characteristic of high response:



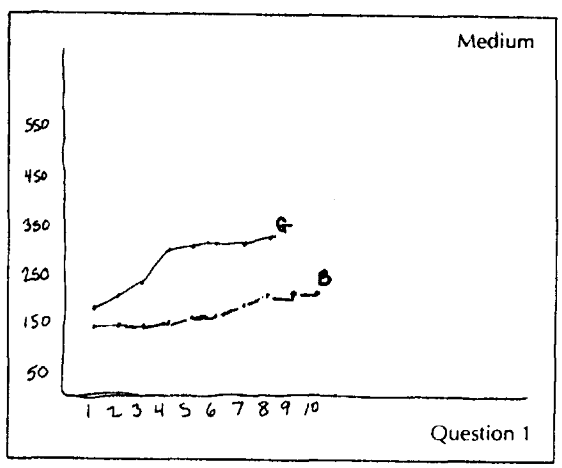
The graph represents the data clearly and accurately, with the scale and intervals chosen appropriately.

The description of the grizzly bears and black bears includes accurate observations about the ranges of the two sets of data and the way each set of data is distributed over its range (that is, there are some comments about center and spread, although these may not be in formal statistical terms).

The general conclusion reached is that the grizzly bears are generally heavier than black bears, but some black bears weigh more than some grizzly bears.

A number or range is chosen that represents the difference between the central values or central clumps of the two sets of data. A median, mean, or less formal measure of center is used (e.g., "Most of the grizzly bears clump around 200 pounds even though there are a few bigger ones and a few smaller ones, so I said that a typical grizzly bear is 200. . .").

Characteristics of the medium response:



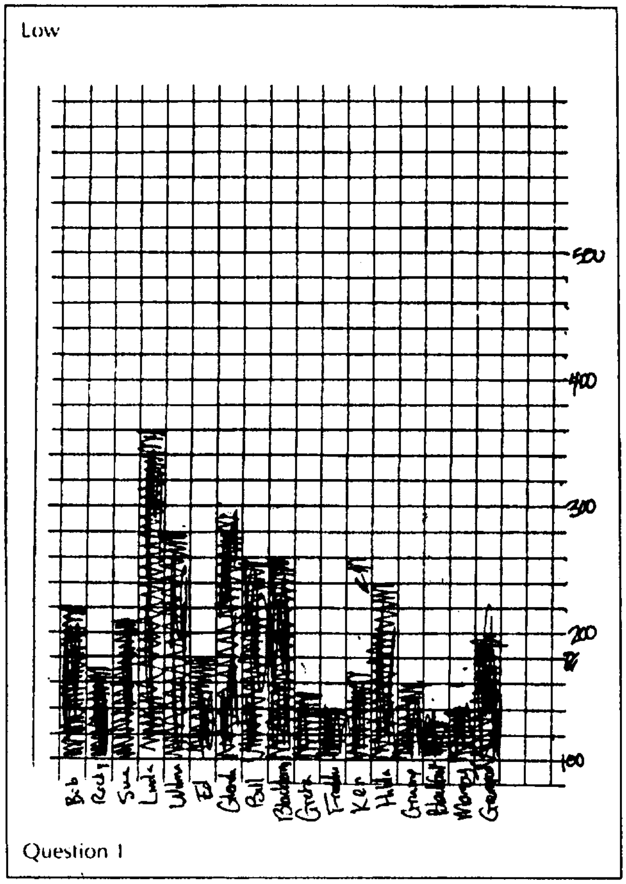
The scale or intervals chosen are not chosen so as to show the data as clearly as possible, or there are a few inaccuracies in plotting the data.

The description of the black bears and grizzly bears does not include some of the important aspects about the range and center of the data.

The general conclusion reached could be interpreted to mean that all grizzly bears weigh more than all black bears (that is, the overlap of the data is not noted).

A reasonable answer is given (that a typical grizzly bear weighs about 30 to 50 pounds more than a typical black bear), but the explanation is inadequate.

Characteristics of the low response:



The graph has major flaws that significantly impede comparisons of the two kinds of bears—for example, incorrectly plotted data, mislabeled axes, or inadequate distinction between the two types of bears.

The description of the data focuses on individual values rather than capturing features of the whole data set.

Either the wrong kind of bear is identified as the heavier one, or no reference is made to the graph at all in support of the conclusion. No attempt is made to consider the "typical" bear of either type; for example, two specific bears are chosen and the difference of their weights reported.

References

The "Used Numbers: Real Data in the Classroom" project at TERC (Technical Education Research Council).

Assessment in A New Compact for Learning

According to *A New Compact for Learning*, the existing State testing program will be revised and will include components such as the following:

> *A **professional evaluation** of the pupil's accomplishments, made by his/her teachers. This evaluation should extend not only to basic skills and knowledge, but also to desirable qualities (such as persistence, creativity, and sensitivity to others) not easily measured by conventional means.*
>
> *A **portfolio** of the pupil's best work, certified by his/her teachers and evaluated by qualified raters.*
>
> ***Examinations** which measure problem-solving skills and the ability to analyze and synthesize as well as factual recall.*

Professional Evaluation

Performance-based assessment strategies that require students . . . to demonstrate their proficiency as they would in real-life situations . . . are attempting to make schools genuinely accountable for helping students acquire the kinds of knowledge, skills, and abilities they will need to use in the world outside of school. Many of these initiatives also share another important characteristic of other countries' examinations: they involve teachers in developing and scoring the assessments, in supervising the development of student work for portfolios, and in examining the performance of their own students and others. Thus, assessment is tied directly to instruction and to the improvement of practice, creating greater knowledge and shared standards across the educational enterprise as a whole.

In order for schools to educate *all* students to their greatest potential, teachers must know as much about students and their learning as they do about subject matter. However, teachers' understandings of students' strengths, needs, and approaches to learning—or about the implications of content and performance standards—are not well supported by external testing programs that send secret, secured tests into the school and whisk them out again for machine scoring that produces numerical quotients many months later.

Curriculum-embedded assessment strategies—that is, assessment woven into the course of instruction—can provide teachers with much more useful classroom information as they engage teachers in evaluating how and what students know and can do in real-life performance situations. Portfolios of student work including extended projects and structured performance tasks help teachers look at how students learn, what they understand deeply, and how they can demonstrate their learning in a variety of different ways. These kinds of assessment strategies create the possibility that teachers not only will develop curriculum aimed at challenging performance skills, but also will use the resulting information about students' learning and performance to shape their teaching in ways that can prove more effective for individual students.

> At the core of the new assessment system proposed by the Curriculum and Assessment Council, then, is the principle that assessment should inform and support teachers' efforts to understand student learning and schools' efforts to improve the educational opportunities they provide.[4]

A Portfolio of Pupil's Best Work

Student portfolios have been commonly used to assess student performance in some disciplines such as art and writing. Although mathematics, science, and technology teachers have often kept folders for students, the use of portfolios in assessment has not been widespread in these disciplines. A portfolio, in contrast to a folder, has more focus and is organized to provide for summative evaluation.

Students as well as teachers should decide on the materials to include in the portfolio. The portfolio should be a showcase for student work and contain a variety of types of work. Examples include projects, problem-solving exercises, investigations, criterion-referenced tests, teacher-developed assessments, student reports, assignments, and awards. The diagram on the following page shows some components that might be part of a mathematics, science, and technology portfolio. The design was developed from a model included in the NCTM (National Council of Teachers of Mathematics) publication, *Mathematics Assessment: Myths, Models, Good Questions, and Practical Suggestions.*

Portfolio assessment provides opportunities for:

- performance beyond factual knowledge
- evaluation over an extended period of time
- students who are poor test takers to demonstrate understanding
- enhancement of students' self-esteem
- demonstration of different learning styles
- an active student role in the assessment process
- an indication of student attitudes toward mathematics, science, and technology
- student self-assessment
- joint student-teacher discussion of progress
- parents and others to gain a broader understanding of student progress

A portfolio can show student progress toward achieving the standards in this draft framework. Portfolio entries can demonstrate the ability to reason, to communicate, to make conjectures, to build logical arguments, to solve problems, to make connections in mathematics, science, and technology, and to carry out interdisciplinary activities.

Educators need time to establish standards of assessment. The portfolio rubrics—detailed descriptions of assessment standards—will very likely vary from school to school. Both the State and the school should play a vital part in helping to define these rubrics.

Examinations

The State's assessments should rely on multiple assessment strategies and tasks—for example, performance tasks, projects, oral and written examinations—and use a set of performance standards that represent different levels of performance (e.g., proficient, highly proficient, and distinguished). These levels of performance should be reported in concrete terms across the many domains of performance in each field, describing the kinds of tasks students can perform at each level in ways that are understandable to students, parents, teachers, and the general public.

The details concerning the State's new assessment system will be determined by Regents policy that will be developed during 1993-94 and subsequently refined and implemented.

An extensive system will be described here.

[4] *Learning-Centered Curriculum and Assessment for New York State.* Report of the New York State Curriculum and Assessment Council to the Commissioner of Education and the Board of Regents. November 1993, pp. 29-30.

INSIDE A MATHEMATICS, SCIENCE, AND TECHNOLOGY PORTFOLIO

The focus in student portfolios is on these items:

- Student thinking
- Growth over time
  (Be sure to date all papers.)
- Interdisciplinary connections
- Student views of themselves as mathematicians, scientists, or engineers
- The problem-solving process

A solution to an open-ended question done as homework—not just a neat set of figures, but showing originality and unusual procedures; alternative technological design solutions; scientific hypotheses

A report of a group project, with comments about the individual's contribution, for example:

- A survey of adult use of mathematics in work
- A review of media use of science
- A presentation of the use of technology in investigating issues and problems

Work from another subject area that relates to mathematics, science, and technology, such as an analysis of data collected and presented in a graph for social studies

A scientific autobiography

A problem made up by the student, with or without a solution

Teacher-completed checklists

Art work and functional models produced by the student, such as string designs, coordinate pictures, scale drawings, maps, computer designs, 3-dimensional prototypes, working models

Work in the student's primary language

Excerpts from a student's daily journal

Notes from an interview—by the teacher or another student. Letters sent as requests for information

A table of contents

Papers that show the student's correction of errors or misconceptions. An analysis of how the student would proceed differently next time

Draft, revised, and final versions of student work on a complex problem, including writing, diagrams, graphs, charts, or whatever is most appropriate

A photo or sketch made by the student (or teacher) of prototypes, or work with manipulatives or with mathematical models of multidimensional figures

A letter from the student to the reader of the portfolio, explaining each item

A description by the teacher of a student activity that displayed understanding of a technological concept

Adapted from *Mathematics Assessment, Myths, Models, Good Questions and Practical Suggestions,* Edited by Jean Kerr Stenmark. Reston, VA. The National Council of Teachers of Mathematics, Inc. 1991, p. 37. Used with permission.

CHAPTER V: MODEL PROGRAMS AND PRACTICES

This chapter is reserved for contributions received from classroom teachers, curriculum developers, and others who are working on programs, practices, and assessments that model the effective integration of mathematics, science, and technology, and the achievement of the standards.

Appendix A
Students with Disabilities

The Board of Regents, through the Part 100 Regulations of the Commissioner, the Action Plan, and *The New Compact for Learning* has made a strong commitment to integrating the education of students with disabilities into the total school program. According to Section 100.2(s) of the Regulations of the Commissioner of Education, "Each student with a handicapping condition as such term is defined in Section 200.1(ii) of this Chapter, shall have access to the full range of programs and services set forth in this Part to the extent that such programs and services are appropriate to such student's special educational needs." Districts must have policies and procedures in place to make sure that students with disabilities have equal opportunities to access diploma credits, courses, and requirements.

The majority of students with disabilities have the intellectual potential to master the curricula content requirements for a high school diploma. Most students who require special education attend regular education classes in conjunction with specialized instruction and/or related services. These students must attain the same academic standards as their nondisabled peers in order to meet these requirements. For this reason, it is very important that at all grade levels students with disabilities conditions receive instruction in the same content areas so as to receive the same informational base that will be required for proficiency on statewide testing programs and diploma requirements.

The teacher providing instruction through this syllabus/curriculum has the opportunity to provide an educational setting which will enable the students to explore their abilities and interests. Instruction may be provided to students with disabilities either by teachers certified in this subject area or by special education teachers. Teachers certified in this subject area would be providing instruction to students with disabilities who are recommended by the Committee on Special Education (CSE) as being able to benefit from instruction in a regular educational setting and are appropriately placed in this setting. Special education teachers may also provide this instruction to a class of students with disabilities in a special class setting.

Teachers certified in the subject area should become aware of the needs of students with disabilities who are participating in their classes. Instructional techniques and materials must be modified to the extent appropriate to provide students with disabilities the opportunity to meet diploma requirements. Information or assistance is available through special education teachers, administrators, the Committee on Special Education (CSE), or a student's Individualized Education Program (IEP).

Additional assistance is available through consultant teacher services. The implementation of this service allows school districts to provide direct and indirect services to students with disabilities who are enrolled full-time in a regular education program. Direct consultant teacher services consist of individualized or group instruction which would provide such students with instructional support in the regular education classroom to help them benefit from their regular education program. Indirect consultant teacher services provides support to the regular education teacher in the modification and development of instruction and evaluation that effectively deals with the specialized needs of students with disabilities.

Strategies for Modifying Instructional Techniques and Materials

1. Prior to having a guest speaker or taking field trips, it may be helpful to structure the situation. Use of a checklist or a set of questions generated by the class will help students focus on relevant information. Accessibility for students with disabilities should be considered when field trips are arranged.

2. The use of computer software may be appropriate for activities that require significant amounts of writing by students.

3. Students with disabilities may use alternative testing techniques. The needed testing modifications must be identified in the student's Individualized Education Program (IEP). Both special and regular education teachers need to work in close cooperation so that the testing modifications can be used consistently throughout the student's program.

4. Identify, define and pre-teach key vocabulary. Many terms in this syllabus are specific and may need continuous reinforcement for some students with disabilities. It would also be helpful to provide a list of these key words to the special education teacher in order to provide additional reinforcement in the special educational setting.

5. Check periodically to determine student understanding of lectures, discussion, demonstrations, etc. and how this is related to the overall topic. Encourage students to express their understanding. It may be necessary to have small group discussions or work with a partner to determine this.

6. Provide students and special education teachers with a tape of lectures that contain substantial new vocabulary content for further review within their special education class.

7. Assign a partner for the duration of a unit to a student as an additional resource to facilitate clarification of daily assignments, timelines for assignments, and access to daily class notes.

8. When assigning long-term projects/reports, provide a timeline with benchmarks as indicators for completion of major project/report sections. Students who have difficulty with organizational skills and time sequence may need to see completion of sections to maintain the organization of a lengthy project/report.

Special education teachers providing this instruction must also become familiar with the goals and objectives of the curriculum. It is important that these teachers provide their students with the same or equivalent information contained in the curriculum.

Regardless of who provides the instruction, the cooperation between teachers of regular and special education programs is essential. It is important for the students as well as the total school environment.

Alternative Testing Techniques

Another consideration in assisting students with disabilities to meet the requirements of regular education is the use of alternative testing techniques. Alternative testing techniques are modifications of testing procedures or formats which provide students with disabilities equal opportunity to participate in testing situations. Such techniques provide the opportunity to demonstrate mastery of skills and attainment of knowledge without being limited or unfairly restricted by the existence of a disability.

The Committee on Special Education (CSE) is responsible for identifying and documenting the student's need for alternative testing techniques. This determination is made when a student is initially referred to the CSE, is reviewed annually for as long as the student receives special education services, and is reviewed when the student is determined to no longer need special education services. **These modifications are to be used consistently throughout the student's educational program.** Principals ensure that students who have been identified by the CSE as disabled are provided the alternative testing techniques which have been recommended by the CSE and approved by the board of education.

Alternative testing techniques which have been specified on student IEPs for use by a student must be used consistently in both special and regular education settings. Regular classroom teachers should be aware of possible alternative testing techniques and should be skilled in their implementation.

The coordination and cooperation of the total school program will assist in providing the opportunity for a greater number of students with disabilities to meet the requirements needed to pursue a high school diploma. The integrated provision of regular education programs, special education programs, remediation, alternative testing techniques, modified teacher techniques and materials, and access to credit through alternatives will assist in enabling such students to pursue the high school diploma to a greater degree. The teacher who provides instruction through this curriculum has a unique opportunity to assist such students in achieving their individual goals.

For additional information on alternative testing procedures, contact:

The New York State Education Department
Office for Special Education Services
Room 309 Education Building
Albany, NY 12234

Infusing Awareness of Persons with Disabilities Through Curriculum

In keeping with the concept of integration, the following subgoal of the Action Plan was established:

> In all subject areas, revisions in the syllabi will include materials and activities related to generic subgoals such as problem solving, reasoning skills, speaking, capacity to search for information, the use of libraries and increasing student awareness of and information about the disabled.

The purpose of this subgoal is to ensure that appropriate activities and materials are available to increase student awareness of disabilities.

This curriculum, by design, includes information, activities, and materials regarding persons with disabilities. Teachers are encouraged to include other examples as may be appropriate to their classroom or the situation at hand. Teachers are also encouraged to assess the classroom environment to determine how the environment may contribute to student awareness of persons with disabilities.

RESPONSE FORM
MATHEMATICS, SCIENCE, AND TECHNOLOGY CURRICULUM FRAMEWORK DRAFT DOCUMENT

The purpose of a Curriculum Framework is to guide local curriculum development, State and local assessments, and professional development. It represents the full array of skills and abilities students should strive for in each subject area.

This response form is being used throughout New York State to collect data on the ***Mathematics, Science, and Technology Curriculum Framework*** draft document.

Please return this form to Paul Scudiere, New York State Education Department, Room 675 EBA, Albany, New York, 12234 by October 30, 1994. Thank you very much for your input. The next version of this document will reflect comments from those who respond.

To help gauge the perspectives of the respondents, please check one or more of the following which apply to you:

1___ Parent of K-12 Student
2___ Teacher (__elem __middle __high school)
3______________ (subject/s taught)
4___ Student
5___ School Administrator
6___ Business Community
7___ Professional Association Member: Teacher or Supervisor
8___ Cultural Institution Representative
9___ School Board Member
10___ Teacher Center Employee
11___ Teacher Union Representative
12___ BOCES Employee
13___ Post-secondary Teacher or Administrator
14___ Interested Reviewer
15___ Public School
16___ Non-public School

If you are interested in continuing your involvement in activities related to the curriculum frameworks, please provide the following information:

Name ______________________________

Office ______________________________

Address ______________________________

____

Telephone: ______________________________

Section I: General Response

Please circle the appropriate value.

1 Does the draft curriculum framework communicate clearly what students K-12 should know and be able to do in mathematics, science, and technology?

1	2	3	4	5
Not At All				**Very Well**

2 What do you like **best** about this draft curriculum framework and its implications for standards for mathematics, science, and technology?

3 What do you like **least** about this draft curriculum framework and its implications for standards for mathematics, science, and technology?

4 What issue(s) need further clarification?

Section II: Specific Response to Standards

These general statements describing each standard are accompanied by a fuller exposition of key concepts and key competencies in the Framework on the pages noted.

Please circle the appropriate value.

1 Standard #1: Analysis, Inquiry and Design
Students will have knowledge, skills, and attitudes that empower them to use mathematical analysis, scientific inquiry, and engineering design, as appropriate, to pose questions, seek answers, and design solutions (pp. 23-30).

Comments:*

A. How important is this standard for **all** students?

1 2 3 4 5

Not Important — **Very Important**

B. How clear is the standard?

1 2 3 4 5

Not Clear — **Very Clear**

2 Standard #2: Systems
Students will acquire an understanding of the basic concepts of systems and their uses in the analysis and interpretation of interrelated phenomena in the real world, within the context of mathematics, science and technology (pp. 31-36).

Comments:

A. How important is this standard for **all** students?

1 2 3 4 5

Not Important — **Very Important**

B. How clear is the standard?

1 2 3 4 5

Not Clear — **Very Clear**

3 Standard #3: Information Resources
Students will use a full range of information systems, including computers, to process information and to network with different school and community resources, such as libraries, people, museums, business, industry, and government agencies (pp. 37-38).

Comments:

A. How important is this standard for **all** students?

1 2 3 4 5

Not Important — **Very Important**

B. How clear is the standard?

1 2 3 4 5

Not Clear — **Very Clear**

* Please use page 6 for additional comments

4 Standard #4: Science
Students will demonstrate knowledge of science's contributions to our understanding of the natural world, including the physical setting, the living environment, and the human organism, and will be aware of the historical development of these ideas (pp.39-44).

Comments:

A. How important is this standard for **all** students?

1 2 3 4 5

Not Important **Very Important**

B. How clear is the standard?

1 2 3 4 5

Not Clear **Very Clear**

5 Standard #5: Technology
Students will acquire the knowledge and skills related to the tools, materials, and processes of technology to create products, services, and environments in the context of human endeavors such as bio-related technologies (agriculture, health), manufacturing, construction (shelter and other structures), transportation, and communication (pp. 45-49).

Comments:

A. How important is this standard for **all** students?

1 2 3 4 5

Not Important **Very Important**

B. How clear is the standard?

1 2 3 4 5

Not Clear **Very Clear**

6 Standard #6: Mathematics
Students will understand and use basic mathematical ideas, including logic, number sense and numeration concepts, operations on numbers, geometry, measurement, probability and statistics, algebra, and trigonometry and be familiar with their uses and application in the real world through problem solving, experimentation, validation, and other activities (pp. 50-55).

Comments:

A. How important is this standard for **all** students?

1 2 3 4 5

Not Important **Very Important**

B. How clear is the standard?

1 2 3 4 5

Not Clear **Very Clear**

Standard	Rating
7 Standard #7: Connecting Themes Students will understand the relationships among mathematics, science, and technology, identify common themes connecting them, and apply these themes to other areas of learning and performance (pp. 57-61). Comments:	**A.** How important is this standard for **all** students? 1 2 3 4 5 **Not Important** … **Very Important** **B.** How clear is the standard? 1 2 3 4 5 **Not Clear** … **Very Clear**
8 Standard #8: Interdisciplinary Problem Solving Students will apply the knowledge and thinking skills of mathematics, science, and technology to address real-life problems and to make informed decisions (pp. 62-64). Comments:	**A.** How important is this standard for **all** students? 1 2 3 4 5 **Not Important** … **Very Important** **B.** How clear is the standard? 1 2 3 4 5 **Not Clear** … **Very Clear**
9 Standard #9: Preparation for the Future Students will develop habits of mind and social and career-related skills in mathematics, science, and technology education classes that will enable them to work productively with others, achieve success in a postsecondary school setting, enter the workplace prepared to achieve success in different jobs, and possess skills necessary for lifelong learning and continuing advancement (pp. 65-67). Comments:	**A.** How important is this standard for **all** students? 1 2 3 4 5 **Not Important** … **Very Important** **B.** How clear is the standard? 1 2 3 4 5 **Not Clear** … **Very Clear**

1 Are there elements of Mathematics, Science, and Technology learning that you think are essential that are not included in these standards?

2 Which elements of the Framework that reflect the common core of Mathematics, Science, and Technology learning should be expected of all students?

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ABOUT THE COVER

Umbilic Torus NC is a captivating combination of Mathematics, Science, and Technology. The surface filling curve texture informs of theorems a century old, yet was cut with space age precision technology. The form itself integrates millennia-old plane geometry cycloid constructions with modern concepts of topology and matrix representations combined with lost wax bronze foundry technology. For more about this sculpture, the artist and scientist, see the book *HELAMAN FERGUSON: Mathematics in Stone and Bronze*, written by Claire Ferguson, and published by Meridian Creative Group, 5178 Station Road, Erie, PA 16510, phone (814) 898-2612.

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