Integrating Mathematics, Science and Technology in the Elementary School

Implementation and Resource Guide

Working Draft
July 1999

The MSTe Project is funded by the National Science Foundation, grant no. ESI-96189862

About the MSTe Project

The MSTe Project is a five-year staff development program funded by the National Science Foundation which is designed to help elementary school teachers integrate their teaching of mathematics, science, and technology in a learner-centered context. Student-driven investigations and design-and-construct activities are the instructional core.

Three institutions — Brookhaven National Laboratory, Hofstra University, and SUNY at Stony Brook — are collaborating with 21 school districts; the Nassau, Suffolk, and Orange-Ulster BOCES; and the New York City Urban Systemic Initiative to conduct the project.

MSTe Project Staff

Dr. Jacqueline Grennon Brooks, Co-Principal Investigator
SUNY at Stony Brook
Dr. David Burghardt, Co-Principal Investigator
Hofstra University
Joanne English Daly, Staff Associate
SUNY at Stony Brook
Michael Hacker, Executive Director
The MSTe Project
Jacqueline Kampf, Administrative Assistant
SUNY at Stony Brook
Dr. Janice Koch, Co-Principal Investigator
Hofstra University
Dr. Thomas Liao, Co-Director
SUNY at Stony Brook
Martha Giraldo Riordan, Project Secretary
Hofstra University
Dr. Karl Swyler, Director of Education Programs
Brookhaven National Laboratory
Dr. Sharon Whitton, Co-Principal Investigator
Hofstra University

For further information, contact:
Jacqueline Kampf
Administrative Assistant
(516) 632-6744
jkampf@ccmail.sunysb.edu

MSTe Project Liaisons

Elsie Chan, NYC Urban Systemic Initiative
Dr. Joan Daly-Lewis, Eastern Suffolk BOCES
Susan M. Killeen, Orange/Ulster BOCES
Dr. Jean Parr, Orange/Ulster BOCES
Gene Silverman, Nassau BOCES

MSTe Project Evaluators

Dr. Penelope Haile
Hofstra University
Dr. Iris Weiss
Horizon Research, Inc.

This is a working draft of the **MSTe Implementation and Resource Guide**. Feedback is sought on the usefulness of these materials. Additional items to be included in these sections are also solicited. Please send comments and submissions for future editions to the Project Editor:

Sue Siegal
2516 Hilltop Road
Schenectady, NY 12309-2436
(518) 372-8612
(518) 372-4015 fax
suesiegal@aol.com

MSTe Leadership Teams Teacher Roster

Nassau County

Long Beach City School District
Joan Benowitz
Faith Moskowitz
Frank Murphy

Mineola UFSD
Nicole DeSantis
Elena-Marie Jackson
Scott McMullen

Oceanside UFSD
Kathy Chapman
Michelle Farber
Donna Migdol

Oyster Bay-East Norwich CSD
Gina Barbato
Regina Furnari
Kathleen Meyer

Plainview-Old Bethpage CSD
Myra Brand
Lynda Lyons
Emily O'Brien

Syosset CSD
Marilyn Cacioppo
Sheila Leitner
Kevin Oswald

Uniondale UFSD
Lisa Graves
Rose Kalman
Cynthia Simmons
Angela Staton

New York City

NYC District 06, Manhattan
Daisy Diaz
Jane Stone
Karli Woods

NYC District 10, Bronx
Paul Lopin
Mary Vaccaro
Lynette Vasquez

NYC District 16, Brooklyn
Ingrid Finch
Nicole Kennedy
Pierre Michel

NYC District 30, Queens
Cynthia Pappas
Kim Riley
Renee Sabbagh

Orange-Ulster

Minisink Valley CSD
Eileen Candito
Tanya DiCarlo

Monroe-Woodbury CSD
James Congelli

Pine Bush CSD
David Kellish
Kimberly Lutz
Virginia Moore

Suffolk County

Copiague CSD
Jodi Foster
Richard Knox
Marie Nicharico

Longwood CSD
Nancy Einbinder
Martha Lackner
Pamela Urso

Mount Sinai CSD
Carolyn Clark
John Costa

Northport-East Northport UFSD
Sandra Dobise
Douglas O'Loughlin
Abby Rosario
Bruce Wnuk

Patchogue-Medford CSD
Frank DiMartino
Linda Eckardt
Wendy Handshaw Power

Smithtown CSD
Cheryl Borden
Lois Rudin
Ernest Ruiz

South Huntington UFSD
Claudia Gary
John McDonald
Daniel Rebori

Westhampton Beach CSD
Katherine Haack
Lynne Marshall

Visit the MSTe Project at
http://www.scied.bnl.gov/sciweb/index1.html

MSTE IMPLEMENTATION AND RESOURCE GUIDE

Part I. Context for MST Integration

Part II. Implementation Strategies for MST

Part III. Shared Professional Growth

Part IV. Choosing Curriculum Materials

Part V. Sample Annotated MST Activities and Assessments

Why Integrate Mathematics, Science, and Technology?

The growth of mathematics, science, and technology in recent decades has had significant effects on human society and the designed world. An important goal of an integrated approach to mathematics, science, and technology education is to prepare students to assume a constructive role as adults.

As citizens in a highly technological society, students must to be able to use mathematics, science, and technology to improve their lives, the lives of others in their community, and the lives of other organisms on the planet. In addition, because so many jobs now demand more knowledge of mathematics, science, and technology, all students need to have access to these fields of study.

In the everyday world, mathematics, science, and technology are not separate and distinct, but are used in combination to analyze and solve problems in research, business, communications, humanities, and the arts. Integrating mathematics, science, and technology education will help students to function in the challenging environment of the 21st century. Other discipline areas such as language arts and social studies can also be included through science, technology, and society units.

There are compelling reasons for integrating the three subjects:

- We cannot explain scientific inquiry well without also discussing how mathematical analysis and engineering design expand the power of such inquiry.
- Today's engineers and technologists need principles and theories produced by scientific inquiry to help design and build optimum technological tools and techniques.
- Many complex ethical issues resulting from interactions of mathematics, science, technology, and society will face citizens of tomorrow. Studying these subjects now will prepare students to deal wisely with issues such as environmental protection and health care.
- Motivation to study mathematics and science is enhanced when students deal directly with real-world applications.

Some Approaches to Mathematics, Science, and Technology Integration

As shown in the models that follow, integrating mathematics, science, and technology can be viewed as a continuum that ranges from changes made by individual classroom teachers, to developing interdisciplinary units, to team teaching mathematics, science, and technology courses and programs.

For teachers who want to strengthen their teaching in relation to the State standards, a way to start might be to meet with other mathematics, science, and technology teachers to think about ways to enrich their own teaching by making connections to the other disciplines.

Questions to ask:

- How can we help our students to make connections between what they learn in our classes and what they are learning in other classes?
- How can we realign units so that students can make associations between what is being taught in the various disciplines?

- How can we integrate the common themes from Standard 6 into the material already being taught?
- Who can we use as resources to help us and our students learn more about the other disciplines?

Teachers who want to take another step in the continuum might want to develop an interdisciplinary unit, either on their own, or with other teachers. A valuable resource for technology education exists in school districts. Technology teachers at the middle school can help elementary teachers who want to strengthen their technology education program. Discussions and brainstorming sessions among mathematics, science, and technology teachers at various levels in districts can help generate ideas and resources for interdisciplinary units.

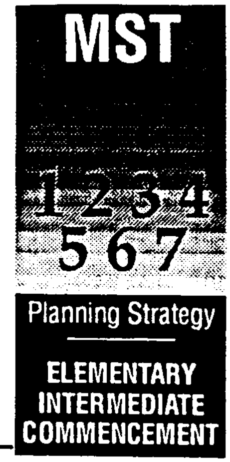
A further step along the continuum is team teaching. Teachers who are interested might begin with one team-taught class. Schools that are furthest along on the integration continuum have developed mathematics, science, and technology courses and programs.

General Principles for Learning in Mathematics, Science, and Technology

Several basic principles provide the foundation for guiding the educational process for K-12 teaching and learning in mathematics, science, and technology. These include:

- 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.
- Mathematics, science, and technology need to be presented in a context appropriate to the student's level of understanding.
- 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.
- The assessment of student progress and achievement must be tied directly to standards and support their attainment.

Source: *NYS Framework for Mathematics, Science, and Technology*



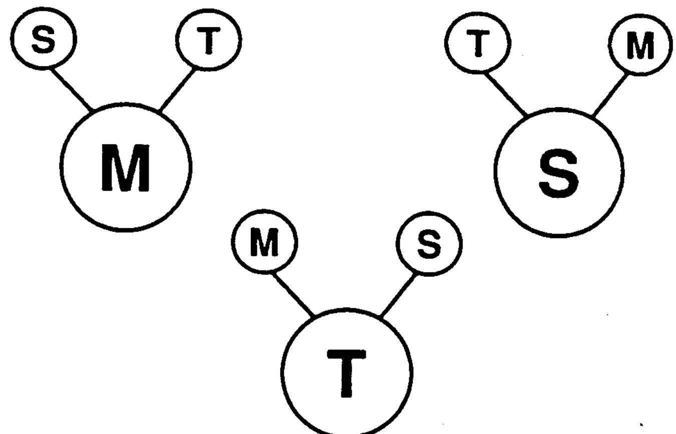
A Continuum of Mathematics, Science, and Technology (MST) Implementation Models

The three models below illustrate ways that schools across the State are integrating mathematics, science, and technology instruction.

MODEL 1

In this model, individual teachers help students make explicit connections between what they learn in a particular M, S, or T class and what they are learning in other classes. (School 14, Yonkers, DeWitt Middle School, Ithaca, and Stuyvesant High School, New York City)

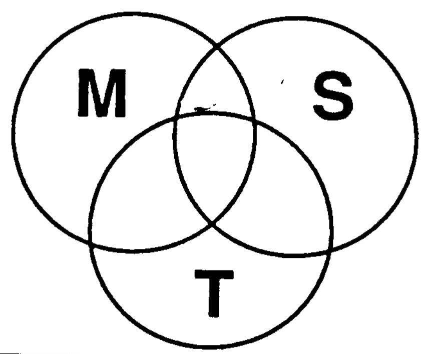
MST and/or STM and/or TMS



MODEL 2

In this model, teachers work together to develop interdisciplinary units. (Pelham Central School District and Smithtown Central School District)

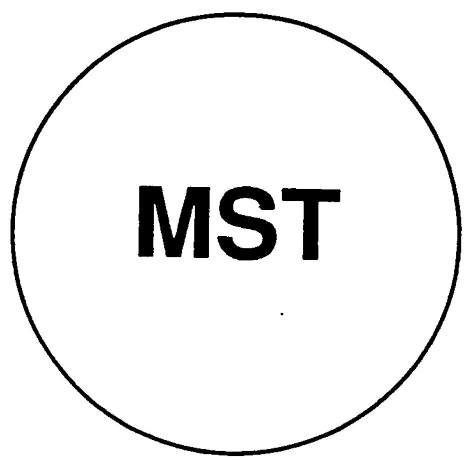
M + S +T+ (MST)



MODEL 3

This model illustrates a fully integrated approach. Students are either block-scheduled into three periods of mathematics, science, and technology or an integrated mathematics, science, and technology course where teachers team teach. (North Colonie Central School District and Bayshore Union Free School District)

MST Integrated Program



Source: *NYS Resource Guide for MST*

A New Paradigm for Math, Science, and Technology Education

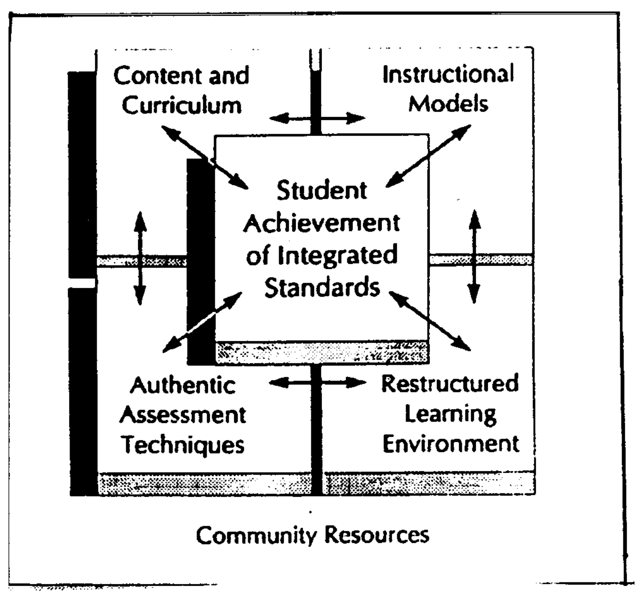
Mathematics, science, and technology, like all disciplines, are in the midst of a knowledge explosion. Technology is making it possible for students to access incredible amounts of information; encyclopedias are available on CD-ROMs and Library of Congress holdings can be accessed through the Internet. 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 insight into the natural and technological world which 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 NYS Framework for MST 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 education 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. Four cornerstones have been identified: Content and Curriculum, Instructional Models, Authentic Assessment Techniques, and Restructuring of the Learning Environment.

The education system must be dynamic. There must be constant interaction between the broad standards and the four cornerstones, as depicted in the diagram. The diagram highlights the importance of using a total systems approach. In order to provide effective instruction to all students, there must be continuing monitoring of whether all four cornerstones are contributing toward the achievement of the standards.



Looking at four cornerstones of the new education system, it is important to understand two things: the learner is at the heart of the system and 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. We should realize that we can shape that future by the decisions we make today concerning how we educate our children.

Source: Dr. Thomas Liao in *NYS Curriculum and Assessment Framework for Mathematics, Science and Technology* (1994)

Content and Curriculum

Mathematics, science, and technology curricula tend to be 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 should address the following: the intrinsic value of knowledge, utility, social responsibility, philosophical value, childhood enrichment, and unifying concepts.

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

Authentic Assessment Techniques

In this framework, the role of assessment is to provide feedback to the student, teacher, parents, and community which 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 assessment techniques 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.

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.

Source: Dr. Thomas Liao in *NYS Curriculum and Assessment Framework for Mathematics, Science and Technology* (1994)

Rationale for Mathematics, Science, and Technology Standards

A revolution in public attitudes about mathematics, science, and technology education is under way. The major national organizations representing mathematics, science, and technology education have 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.

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 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 the standards. The MST Standards reflect a serious statewide attempt to promote interconnectedness. They encourage the best pedagogical practice, particularly with respect to constructivist, inquiry- and design-based teaching and learning, and diversified methods of assessment.

The standards that are relevant to the MSTe Project are One, Six, and Seven.

Standard One

Students will use mathematical analysis, scientific inquiry, and engineering design, as appropriate, to pose questions, seek answers, and design solutions.

Standard Six

Students will understand the relationships and common themes that connect mathematics, science, and technology and apply the themes to these and other areas of learning.

Standard Seven

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

Source: Edited from the *NYS Curriculum and Assessment Framework for Mathematics, Science, and Technology* and the Learning Standards for Mathematics, Science, and Technology

The importance of connecting mathematics, science, and technology to encourage and promote science literacy has been spearheaded by the science education reform movement. Major national projects, including Science For All Americans and the National Science Education Standards (NSES), as well as the National Council of Teachers of Mathematics (NCTM) Standards, point to the need to contextualize teaching and learning. *Science for All Americans* is based on the belief that the "science-literate person is one who is aware that science, mathematics and technology are interdependent human enterprises with strengths and limitations." NSES promotes the coordination of science and mathematics programs to enhance students' use and understanding of mathematics in the study of science. It includes science and technology standards at grades K-4, 5-8, and 9-12 in the belief that "learning how to teach science, mathematics and technology by studying connections and interdependence will enhance the science literacy of teachers and their students."

Research shows that connected learning appeals to educators because it mirrors the real world, provides links among subject areas, interests and motivates students, fosters collaboration among teachers, and creates networking throughout the school. knowledge to occupational or life settings. Yet, individuals do not predictably use knowledge learned in school in everyday practice, nor do they use everyday knowledge in school settings. Most importantly, learners do not predictably transfer learning across school subjects. Context is critical for understanding and thus for learning.

Two important shared beliefs underlie reform in science education: (1) students should make real-world connections by exploring how science and technology affect their lives, and (2) instruction should integrate science content with other subjects. Further, a natural starting point in mathematics is an integrated approach. Problems and examples should come from everyday life and connect mathematics to the real world.

Students need to learn from contexts that are real-world, graspable, and self-evidently meaningful. The exemplary curriculum materials to be used in the MSTe Project are replete with opportunities for integrative, inquiry- and design-based problem-solving activity that can help students construct knowledge through physical interaction with their environment. Elementary school children learn best through concrete experiences. It is therefore quite appropriate that MST programs be initiated at the elementary school level where children begin to develop perceptions of themselves as competent learners in mathematics, science and technology and where teachers are responsible for all three subject areas.

MST and the New York State Framework

Recently, a great deal of attention has been given to the links among mathematics, science, and technology. One movement in curriculum transformation, sometimes called the MST initiative, involves truly integrating the three disciplines in curriculum planning. MST stresses the fact that math, science, and technology are interdependent human enterprises. MST promotes science literacy by bringing technology education - the entire concept of engineering design - into the direct support of both science and mathematics activities. It also stresses the use of inquiry and design in problem-solving activities.

The MST initiative is making an important impact of the development of elementary school curricula. In New York State, elementary teachers are urged to explore their elementary science curriculum and "MST" it. That means reviewing the problem-solving investigations with respect to the following criteria:

- What is the nature of the problem-solving activities in science?
- Where does mathematics present itself in these activities?
- Are children expected to design a process or a product as part of their investigations?
- What is the nature of students' access to computer information systems during their investigations?
- How are science ideas linked to mathematics and technology?

Developing Curriculum Units

Typically, a unit of study includes several lessons designed around a central theme or topics. Using science as an example, a unit plan usually consists of the following:

- The science ideas behind the unit
- The activities included in the unit
- The lesson plans for the unit

Sometimes unit plans also include a description of the assessment strategies.

Aligning a Unit of Study with the Standard

Developing a unit of study from the guiding principles in a content standard involves the following steps:

1. Identifying the topic and its relationship to the standard.
2. Identifying the science ideas behind this topic.
3. Exploring activity books and other resources relating to the topic.
4. Designing lessons that allow children to explore their own ideas and permit the teacher to extend the activities as needed.
5. Indicating connections with mathematics, technology, literature, and social studies.

Source: Koch, Janice. *Science Stories: Teachers and Children as Science Learners. (1999)*

Selecting Activities

If you are selecting activities for a unit, you should follow the same criteria as you use for individual lessons. Ask yourself questions like these:

- Does the activity lend itself to individual thinking and problem solving?
- Does the activity match the science idea expressed by the unit?
- Are the materials accessible?
- Is the activity student centered or teacher centered?

You are looking for science activities that encourage individual explorations of phenomena. Commercial materials and kits can be useful as long as you frame the activity in a way that allows students to make decisions about the plan of their investigations. You will also come across your own activity books as well as Internet resources.

What Is Missing?

When you rely solely on a national or state standard to guide your school's or your class's elementary science curriculum, you miss a great deal of the local influence that ought to contribute to the students' science experiences. Who your students are, how they experience nature, where they live, what region of the country your school is located in - all of these considerations should help you frame your units of study.

Remember, too, to explore the personal lives that your students live. Are they hungry? Poor! Overindulged? Disabled? Middle class? How will you use the curriculum to help students to make meaning in the context of their own lives? That is the major role of your science curriculum: to engage students in their own learning, relate science experiences to the students' lives, and help students explore and draw conclusions. Certainly, national documents should help you understand the range of topics and ideas that are appropriate. But what is best for your students remains a local decision.

> *Curriculum - any curriculum - is a lifeless document. You, the teacher, give it life when you use it to guide your students' experiences.*

Source: Koch, Janice. *Science Stories: Teachers and Children as Science Learners. (1999)*

Standard 1—Analysis, Inquiry, and Design

Intermediate

Mathematical Analysis

1. Abstraction and symbolic representation are used to communicate mathematically.

Students:

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

2. Deductive and inductive reasoning are used to reach mathematical conclusions.

Students:

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

This is evident, for example, when students:

▲ predict the next triangular number by examining the pattern 1, 3, 6, 10, ❒.

3. Critical thinking skills are used in the solution of mathematical problems.

Students:

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

Key ideas are identified by numbers (1).
Performance indicators are identified by bullets (•).
Sample tasks are identified by triangles (▲).

Source: NYS MST Learning Standards

Scientific Inquiry

1. The central purpose of scientific inquiry is to develop explanations of natural phenomena in a continuing, creative process.

Students:

- **formulate questions independently with the aid of references appropriate for guiding the search for explanations of everyday observations.**
- **construct explanations independently for natural phenomena, especially by proposing preliminary visual models of phenomena.**
- **represent, present, and defend their proposed explanations of everyday observations so that they can be understood and assessed by others.**
- **seek to clarify, to assess critically, and to reconcile with their own thinking the ideas presented by others, including peers, teachers, authors, and scientists.**

This is evident, for example, when students:

▲ *After being shown the disparity between the amount of solid waste which is recycled and which could be recycled,** students working in small groups are asked to explain why this disparity exists. They develop a set of possible explanations and to select one for intensive study. After their explanation is critiqued by other groups, it is refined and submitted for assessment. The explanation is rated on clarity, plausibility, and appropriateness for intensive study using research methods.

2. Beyond the use of reasoning and consensus, scientific inquiry involves the testing of proposed explanations involving the use of conventional techniques and procedures and usually requiring considerable ingenuity.

Students:

- **use conventional techniques and those of their own design to make further observations and refine their explanations, guided by a need for more information.**
- **develop, present, and defend formal research proposals for testing their own explanations of common phenomena, including ways of obtaining needed observations and ways of conducting simple controlled experiments.**
- **carry out their research proposals, recording observations and measurements (e.g., lab notes, audio tape, computer disk, video tape) to help assess the explanation.**

This is evident, for example, when students:

▲ develop a research plan for studying the accuracy of their explanation of the *disparity between the amount of solid waste that is recycled and that could be recycled.** After their tentative plan is critiqued, they refine it and submit it for assessment. The research proposal is rated on clarity, feasibility and soundness as a method of studying the explanations' accuracy. They carry out the plan, with teacher suggested modifications. This work is rated by the teacher while it is in progress.

Students will use mathematical analysis, scientific inquiry, and engineering design, as appropriate, to pose questions, seek answers, and develop solutions.

3. The observations made while testing proposed explanations, when analyzed using conventional and invented methods, provide new insights into phenomena.

Students:

- **design charts, tables, graphs and other representations of observations in conventional and creative ways to help them address their research question or hypothesis.**
- **interpret the organized data to answer the research question or hypothesis and to gain insight into the problem.**
- **modify their personal understanding of phenomena based on evaluation of their hypothesis.**

This is evident, for example, when students:

▲ carry out their plan making appropriate observations and measurements. They analyze the data, reach conclusions regarding their explanation of the *disparity between the amount of solid waste which is recycled and which could be recycled.**, and prepare a tentative report which is critiqued by other groups, refined, and submitted for assessment. The report is rated on clarity, quality of presentation of data and analyses, and soundness of conclusions.

Engineering Design

1. Engineering design is an iterative process involving modeling and optimization finding the best solution within given constraints which is used to develop technological solutions to problems within given constraints.

Students engage in the following steps in a design process:

- **identify needs and opportunities for technical solutions from an investigation of situations of general or social interest.**
- **locate and utilize a range of printed, electronic, and human information resources to obtain ideas.**
- **consider constraints and 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; and explain why the chosen solution is optimal.**
- **develop plans, including drawings with measurements and details of construction, and construct a model of the solution, exhibiting a degree of craftsmanship.**
- **in a group setting, test their solution against design specifications, present and evaluate results, describe how the solution might have been modified for different or better results, and discuss tradeoffs that might have to be made.**

This is evident, for example, when students:

▲ reflect on the need for alternative growing systems in desert environments and design and model a hydroponic greenhouse for growing vegetables without soil.

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

▲ design a model vehicle (with a safety belt restraint system and crush zones to absorb impact) to carry a raw egg as a passenger down a ramp and into a barrier without damage to the egg.

▲ assess the performance of a solution against various design criteria, enter the scores on a spreadsheet, and see how varying the solution might have affected total score.

* A variety of content-specific items can be substituted for the italicized text

Standard 6—Interconnectedness: Common Themes Elementary

Systems Thinking

1. Through systems thinking, people can recognize the commonalities that exist among all systems and how parts of a system interrelate and combine to perform specific functions.

Students:
- **observe and describe interactions among components of simple systems.**
- **identify common things that can be considered to be systems (e.g., a plant population, a subway system, human beings).**

Models

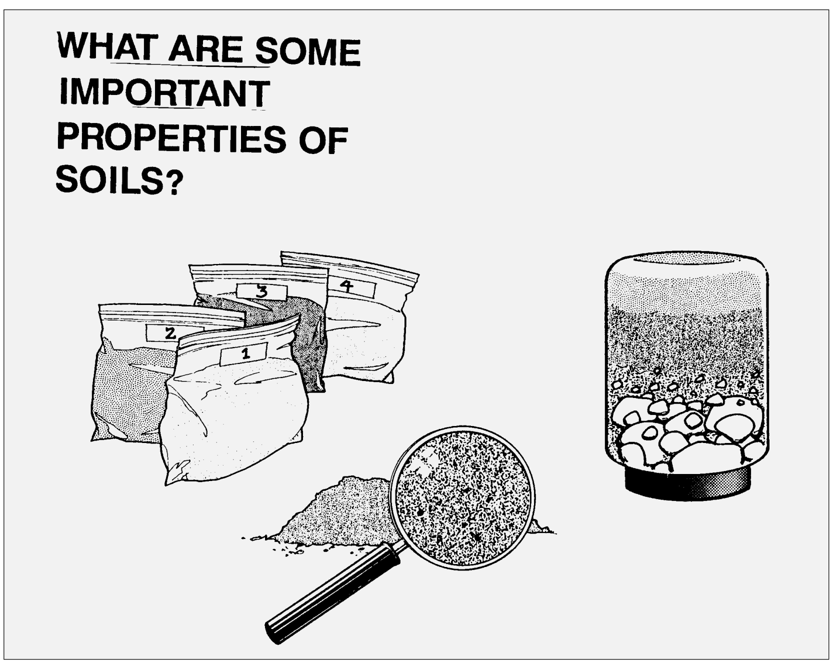
2. Models are simplified representations of objects, structures, or systems used in analysis, explanation, interpretation, or design.

Students:
- **analyze, construct, and operate models in order to discover attributes of the real thing.**
- **discover that a model of something is different from the real thing but can be used to study the real thing.**
- **use different types of models, such as graphs, sketches, diagrams, and maps, to represent various aspects of the real world.**

This is evident, for example, when students:

▲ compare toy cars with real automobiles in terms of size and function.
▲ model structures with building blocks.
▲ design and construct a working model of the human circulatory system to explore how varying pumping pressure might affect blood flow.
▲ describe the limitations of model cars, planes, or houses.
▲ use model vehicles or structures to illustrate how the real object functions.
▲ use a road map to determine distances between towns and cities.

Sample Problem/Activity



Key ideas are identified by numbers (1).
Performance indicators are identified by bullets (•).
Sample tasks are identified by triangles (▲).

Students will understand the relationships and common themes that connect mathematics, science, and technology and apply the themes to these and other areas of learning.

Magnitude and Scale

3. The grouping of magnitudes of size, time, frequency, and pressures or other units of measurement into a series of relative order provides a useful way to deal with the immense range and the changes in scale that affect the behavior and design of systems.

Students:

- **provide examples of natural and manufactured things that belong to the same category yet have very different sizes, weights, ages, speeds, and other measurements.**
- **identify the biggest and the smallest values as well as the average value of a system when given information about its characteristics and behavior.**

This is evident, for example, when students:

▲ compare the weight of small and large animals.
▲ compare the speed of bicycles, cars, and planes.
▲ compare the life spans of insects and trees.
▲ collect and analyze data related to the height of the students in their class, identifying the tallest, the shortest, and the average height.
▲ compare the annual temperature range of their locality.

Equilibrium and Stability

4. Equilibrium is a state of stability due either to a lack of changes (static equilibrium) or a balance between opposing forces (dynamic equilibrium).

Students:

- **cite examples of systems in which some features stay the same while other features change.**
- **distinguish between reasons for stability—from lack of changes to changes that counterbalance one another to changes within cycles.**

This is evident, for example, when students:

▲ record their body temperatures in different weather conditions and observe that the temperature of a healthy human being stays almost constant even though the external temperature changes.
▲ identify the reasons for the changing amount of fresh water in a reservoir and determine how a constant supply is maintained.

Sample Problem/Activity

What can I learn about my body?

CONTENT UNDERSTANDINGS
■ *Soil consists of weathered rock fragments that contain organic material*

➢ How do your results compare to your classmates' results?
➢ What factors do you think could account for the differences?
➢ Who would benefit from the information you gathered and how?
➢ What other information do you think would complete your knowledge of your body?
➢ Are there some data on your form that you would rather keep confidential? Which data?
➢ Who should and should not have access to this information? Give reasons for your answers.

Source: NYS MST Learning Standards

Standard 6—Interconnectedness: Common Themes Elementary

Patterns of Change

5. Identifying patterns of change is necessary for making predictions about future behavior and conditions.

Students:

- **use simple instruments to measure such quantities as distance, size, and weight and look for patterns in the data.**
- **analyze data by making tables and graphs and looking for patterns of change.**

This is evident, for example, when students:

▲ compare shoe size with the height of people to determine if there is a trend.
▲ collect data on the speed of balls rolling down ramps of different slopes and determine the relationship between speed and steepness of the ramp.
▲ take data they have collected and generate tables and graphs to begin the search for patterns of change.

Optimization

6. In order to arrive at the best solution that meets criteria within constraints, it is often necessary to make trade-offs.

Students:

- **determine the criteria and constraints of a simple decision making problem.**
- **use simple quantitative methods, such as ratios, to compare costs to benefits of a decision problem.**

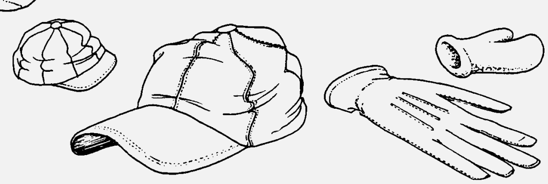
This is evident, for example, when students:

▲ describe the criteria (e.g., size, color, model) and constraints (e.g., budget) used to select the best bicycle to buy.
▲ compare the cost of cereal to number of servings to figure out the best buy.

Sample Problem/Activity

Ask each student to measure the length of the head and the height of three adults and three children (two years old or younger) as an outside assignment. Show them how to calculate the ratio of head length to height. With the class, calculate the average ratio for the children and for the adults.

➢ How does the average ratio for the children compare to that for the adults?
➢ How can we describe in words the change in ratios?
➢ What does this tell us about human growth and development?



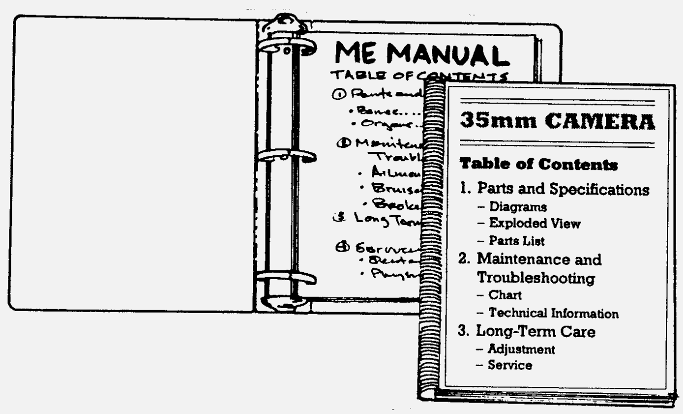
Key ideas are identified by numbers (1).
Performance indicators are identified by bullets (•).
Sample tasks are identified by triangles (▲).

Students will understand the relationships and common themes that connect mathematics, science, and technology and apply the themes to these and other areas of learning.

Sample Problem/Activity

Why would I need an owner's manual?

Students will be able to describe similarities and differences between a manual they create for a device and a personal manual they will create throughout the course of this module and perhaps beyond.



Interdisciplinary Connections

These activities focus on devices as technologies:

➤ **Technology:** Compare electronics information about several types of devices, and account for their similarities and differences.

➤ **Social Studies:** Talk to a lawyer, paralegal, or representative of the Better Business Bureau about written and implied warranties.

➤ **Language Arts:** Develop a second version of your manual that contains a limited number of technical words. Consult your language arts teacher, a children's writer, or a technical writer for assistance in using this kind of controlled approach to manual writing.

➤ **Mathematics:** Locate and read selected magazine articles to determine the nature and extent of the market in various devices. Prepare graphs and charts that show relative percentages of kinds of goods sold and other pertinent information.

➤ **Health:** Interview a nurse, audiologist, pediatrician, or other health specialist regarding hearing losses associated with one or more entertainment devices.

➤ **Home and Career Skills:** Conduct a survey of the electronic devices in your home, including entertainment and nonentertainment devices. Compare your results with an informal survey of one or more older persons regarding electronic devices used in a typical home in the early sixties.

➤ **Foreign Languages and Cultures:** Look through a number of owners' manuals at home or at a car dealership or electronics store. Note whether these manuals are written only in English or in other languages as well. Try to explain why the manufacturer chose certain languages.

Standard 7—Interdisciplinary Problem Solving Elementary

Connections

1. The knowledge and skills of mathematics, science, and technology are used together to make informed decisions and solve problems, especially those relating to issues of science/technology/society, consumer decision making, design, and inquiry into phenomena.

Students:

- **analyze science/technology/society problems and issues that affect their home, school, orcommunity, and carry out a remedial course of action.**
- **make informed consumer decisions by applying knowledge about the attributes of particular products and making cost/benefit tradeoffs to arrive at an optimal choice.**
- **design solutions to problems involving a familiar and real context, investigate related science concepts to inform the solution, and use mathematics to model, quantify, measure, and compute.**
- **observe phenomena and evaluate them scientifically and mathematically by conducting a fair test of the effect of variables and using mathematical knowledge and technological tools to collect, analyze, and present data and conclusions.**

This is evident, for example, when students:

▲ develop and implement a plan to reduce water or energy consumption in their home.

▲ choose paper towels based on tests of absorption quality, strength, and cost per sheet.

▲ design a wheeled vehicle, sketch and develop plans, test different wheel and axle designs to reduce friction, chart results, and produce a working model with correct measurements.

▲ collect leaves of similar size from different varieties of trees, and compare the ratios of length to width in order to determinet whether the ratios are the same for all species.

Strategies

2. Solving interdisciplinary problems involves a variety of skills and strategies, including effective work habits; gathering and processing information; generating and analyzing ideas; realizing ideas; making connections among the common themes of mathematics, science, and technology; and presenting results.

Students participate in an extended, culminating mathematics, science, and technology project. The project would require students to:

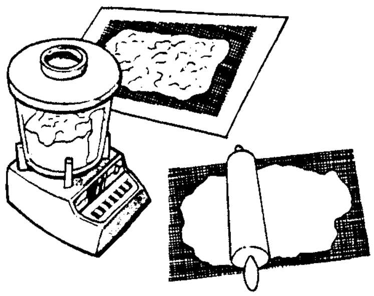
- **work effectively**
- **gather and process information**
- **generate and analyze ideas**
- **observe common themes**
- **realize ideas**
- **present results**

This is evident, for example, when students, addressing the issue of solid waste at the school in an interdisciplinary science/technology/society project:

▲ use the newspaper index to find out about how solid waste is handled in their community, and interview the custodial staff to collect data about how much solid waste is generated in the school, and they make and use tables and graphs to look for patterns of change. Students work together to reach consensus on the need for recycling and on choosing a material to recycle—in this case, paper.

▲ investigate the types of paper that could be recycled, measure the amount (weight, volume) of this type of paper in their school during a one-week period, and calculate the cost. Students investigate the processes involved in changing used paper into a useable product and how and why those changes work as they do.

▲ using simple mixers, wire screens, and lint, leaves, rags, etc., students recycle used paper into useable sheets and evaluate the quality of the product. They present their results using charts, graphs, illustrations, and photographs to the principal and custodial staff.



Key ideas are identified by numbers (1).
Performance indicators are identified by bullets (•).
Sample tasks are identified by triangles (▲).

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

Skills and Strategies for Interdisciplinary Problem Solving

Working Effectively: Contributing to the work of a brainstorming group, laboratory partnership, cooperative learning group, or project team; planning procedures; identify and managing responsibilities of team members; and staying on task, whether working alone or as part of a group.

Gathering and Processing Information: Accessing information from printed media, electronic data bases, and community resources and using the information to develop a definition of the problem and to research possible solutions.

Generating and Analyzing Ideas: Developing ideas for proposed solutions, investigating ideas, collecting data, and showing relationships and patterns in the data.

Common Themes: Observing examples of common unifying themes, applying them to the problem, and using them to better understand the dimensions of the problem.

Realizing Ideas: Constructing components or models, arriving at a solution, and evaluating the result.

Presenting Results: Using a variety of media to present the solution and to communicate the results.

Sample Problem/Activity

How much of Earth's water is readily available for human consumption?

Student Worksheet

Category	Percentage of Total Water in the World	Freshwater/Salt Water
freshwater lakes	0.0090	freshwater
saltwater lakes	0.0080	salt water
rivers	0.0001	
groundwater	0.6250	
sea ice and glaciers	2.1500	
atmospheric water vapor	0.0010	
oceans	97.2000	

1. As you conduct your library research, complete the chart above by filling in the Fresh-water/Salt Water column with either the term "freshwater" or the term "salt water."

2. Represent the information in the first two columns by constructing either a two- or three-dimensional model.

Comments:

Constructivism

Constructivism is a theory of learning that strikes at the very heart of what teachers teach and how students learn. Constructivism assumes that the quest for meaning is the primary motivation for learners of all ages.

When teachers apply theories of constructivism in the classroom, students are challenged to construct their own meaning related to the concepts they are investigating in school. That is, students transform their ideas through the construction of new understandings that provide a scaffolding for further learning. As a result, students develop deeper understandings of concepts, ideas, objects, and phenomena and the relationships among them. They search for patterns and make connections because looking for patterns and building connections provides intrinsic intellectual motivation to look for more patterns and build more connections. This is what learning is.

In the traditional classroom, learning experiences typically are structured around the acquisition of discrete bits of knowledge. Students often memorize facts and formulas in order to get the right answers on the test. They add to their quantitative knowledge base, but how new information fits in with what they already know is rarely considered.

Although many in the United States despair that today's students do not know enough, just adding more pieces of information to their storehouse of knowledge does little to help them think broadly and deeply. Moreover, they quickly forget much of what they learn because it has little meaning for them.

Too often, high school students graduate with a shallow grasp of ideas, which does not prepare them for theory building. In a world that grows ever more complex, such superficial understanding is not sufficient.

From the constructivist point of view, knowledge is dynamic and always in flux, as the brain makes meaning by refining mental models based on new information. A visit to a constructivist classroom reveals the excitement of students engaged in inquiry and problem solving, going far beyond the expected, applying prior learnings creatively, clearly motivated to learn.

Source: Jackie Grennon Brooks, SUNY at Stony Brook

Comparison of the Two Ways of Learning

Traditional	Constructivist
Students are presented with facts about topics.	Students ask open-ended questions and formulate their own questions about topics.
Students are provided with predetermined patterns.	Students search for patterns.
Students memorize theories.	Students investigate and build theories.
Students learn about social studies, English language arts, science, technology, etc.	Students are geographers, scientists, poets, mathematicians, product designers, etc.
Teachers build sequential lessons around topics and regulate the pace according to student skills.	Teachers pose broad questions around big ideas and customize lessons according to student thinking.
Assessment is separate from teaching/learning and occurs mostly through testing.	Assessment is interwoven with teaching and occurs through teacher observations of student exhibitions and portfolios.
Students primarily work alone.	Students primarily work in groups.

Source: Jackie Grennon Brooks, SUNY at Stony Brook

Five Overarching Principles of Constructivist Teaching

1. Pose Problems of Emerging Relevance

The nature of the initial problems posed by the teacher influences the depth to which students can search for answers. Posing problems of emerging relevance and searching for windows into students' thinking can create a classroom setting in which the teacher and the student jointly search for new knowledge.

2. Structure Lessons Around Primary Concepts or "Big" Ideas,
not facts and skills

Learning occurs in context. Focusing on discrete information or specific skills makes sense only when the student has a context in which to learn the skills and consider the information.

3. Seek and Value Students' Points of View

Understanding the students' points of view helps the teacher determine where and how instruction can facilitate learning.

4. Adapt Curriculum to Challenge Students' Suppositions

The opportunity to reflect on one's present assumptions, premises, beliefs, or conceptualizations can facilitate cognitive growth. When teachers design lessons that provoke students to confront their initial suppositions, teachers maximize the likelihood of student learning.

5. Assess Student Learning in the Context of Teaching

Set up systems and settings in which student can exhibit work and share ideas with classmates. Use nonjudgmental responses when responding to students' work.

Source: Jackie Grennon Brooks, SUNY at Stony Brook

Descriptors of Constructivist Teaching Practices

1. Use raw data and primary sources, along with manipulative, interactive and physical materials.

2. When framing tasks, use cognitive terminology, such as classify, analyze, predict, create, and so on.

3. Allow student thinking to drive lessons by shifting instructional strategies or altering content based on student responses.

4. Inquire about students' understandings of concepts before sharing your own understandings of those concepts.

5. Ask open-ended questions of students. Encourage students to ask questions of others.

6. Seek elaboration of students' initial responses.

7. Engage students in experiences that might engender contradictions to students' initial hypotheses and then encourage a discussion.

8. Allow wait time after posing questions.

9. Provide time for students to construct relationships and create metaphors.

Your charge as a teacher:
Create circumstances, events, and experiences so that learners can construct meaning that contributes to informed understandings of how the world works. How does this view of the teacher's role differ from the transmission model of teaching and the direct instruction design of lesson planning?

Also consider:
What norms, practices, and structures in your school district either assist or interfere with learning?
What role do you think you can play in your district to help move some of the norms, practices, and structures that interfere with learning out of the way?

Source: Jackie Grennon Brooks, SUNY at Stony Brook

In *On Knowing*, (1971) author Jerome Bruner invites us to consider this perspective:

> One cannot 'cover' any subject in full, not even in a lifetime, if coverage means visiting all the facts and events and morsels. Subject matter presented so as to emphasize its structure will perforce be of that generative kind that permits reconstruction of the details or, at very least, prepares a place into which the details, when encountered, can be put. (p. 121)

> Finally, it is as true today as it was when Dewey wrote that one cannot foresee the world in which the child we educate today will live. Informed powers of mind and a sense of potency in action are the only instruments we can give the child that will be invariable across the transformations of time and circumstance. The succession of studies that we give the child in the ideal school need be fixed in only one way: whatever is introduced, let it be pursued continuously enough to give the student a sense of the power of mind that comes from a deepening of understanding. It is this, rather than any form of extensive coverage, that matters most. (p. 122)

Creating an Environment for Cooperative Learning

Scientific inquiry-the processes of investigation, reflection, and further investigation-benefits greatly from the collaboration of several people. Four important questions surround the small-group model of teacher and student interaction:

1. How do small group investigations in science relate to what educators call cooperative learning?
2. In what ways is small group learning consistent with constructivist views of learning?
3. In what ways is small group learning consistent with the way science and scientists operate?
4. How can I set up small group learning in my own classroom?

Cooperative Learning Groups

A great deal of important research has been done on cooperative learning, which can be defined to mean students' working together in groups to accomplish shared learning goals. Studies have shown a variety of both social and educational benefits from cooperative learning. For example, cooperative learning helps students retain more conceptual knowledge. It also fosters a classroom climate in which students interact with each other in ways that promote each student's learning (Johnson & Johnson, 1994).

It is important to recognize, though, that cooperative learning, as the researchers in this field define it, is not just any small group instruction. A cooperative learning group is an arrangement in which a group of students, usually of mixed ability, gender, and ethnicity, work toward the common goal of promoting each other's and the group's success. In other words, in a cooperative learning group, each student is responsible for his or her own learning and the group's learning.

There are many ways to structure such learning groups. One basic distinction is between formal and informal groups. In formal cooperative learning groups, the group stays together until the task is done. In informal groups, the commitment is for a shorter term, as when each student checks with a neighbor to see if the neighbor understood (Johnson & Johnson, 1994, p. 100). The groups described here involve formal learning groups, which stay together until the problem is solved, the model is built, or the task is accomplished.

Constructivism and Small Group Learning

Cooperative learning groups encourage the very constructivist learning processes that are at the heart of gaining conceptual knowledge in science. In such groups, students have the opportunity to engage in discussion with others about their ideas, discover differences between their own explanations and others', and defend their position or alter their thinking as the group strives for consensus. Why is this interaction so important for learning? There are may reason, but here we will concentrate on three: reflection, the social context of learning, and the implications of cultural diversity and gender.

Cooperative Learning and Reflection

For students to learn science best, science teaching and science learning rely on the active participation of students. But students must be mentally active as well as physically engaged. Reflective mental processes must accompany the concrete activities. Small-group cooperative learning foster these all-important processes of reflection. When students exchange and clarify ideas with their peers, plan an investigation, or refine their observations and conclusions, their minds are constantly engaged. Each student is prodded to more reflection by the inferences and opinions of others. The collaborative problem solver goes further in constructing new ideas and becomes better prepared for higher levels of thinking.

Learning in a Social Context

Our understandings of the world are constructed in a social context. Even if you disagree fervently with your neighbor about, say, the value of exploring the moon, you both are working with many similar concepts, including understandings of what and where the moon is and what kinds of explorations are feasible. You are both using similar language.

In the same way, students' construction of new science explanations and theories is influenced by the social communication and language norms of our society. Peer communication in a small group helps the group members find a common language with which to express their meaning, and this process promotes their learning. For example, in a lesson on density, the textbook might say, "Density is the mass divided by the volume." This type of decontextualized language can be baffling to many learners. But in a small group conversation, the students may talk about how much 100 milliliters of corn syrup weighs and whether they think the corn syrup is denser than corn oil. One student may then weigh 100 milliliters of corn oil and find out that it weighs less than the corn syrup. As this more contextualized meaning for density emerges from the common social discourse of the small learning group, each student can develop a more personalized, deeper understanding of the science idea.

Cultural Diversity and Gender in Cooperative Learning

Images of scientists have traditionally excluded women and minorities. We know, too, that students who see themselves as marginal in a large group do not readily participate. Thus it is not surprising that girls and students of minority ethnic and cultural groups all too often distance themselves during science lessons, contributing little and learning little.

Cooperative small-group learning activities can help sole the problem. For culturally diverse learners and for girls in science, these activities attend to their academic needs far better than individual learning activities (Barba, 1998). The climate of support created by cooperative learning groups encourages the participation of students whoa re less likely to volunteer and interact in a whole-class situation. Getting culturally diverse students involved brings benefits to everyone else in the group by expanding knowledge and leading students to develop further questions to investigate.

Scientific Investigation and Group Learning

In the adult world, scientific investigation is a social process. Scientific researchers collaborate with one another all the time. They work on teams; they share references to important articles; they access others' research through electronic communication and the Internet.

Classroom science learning groups are a real-life model of the collaboration necessary for true scientific inquiry to occur. They help eliminate the false stereotype of the lone scientist in a remote laboratory. They promote the kind of interchange and teamwork that are essential for scientific problem solving. Moreover, by fostering interactions among students who normally would not be relating to one another, they widen the range of classroom investigations. The more diverse the perspectives are on nature, the more possibilities there are for thorough explorations of natural phenomena. In addition, scientists agree that the more diverse the nature of observations and inferences is, the greater is the possibility that an accurate idea will emerge in the conversation.

Structuring Cooperative Learning Groups in Your Classroom

There are many different ways of structuring small learning groups. No matter how you do it, however, some questions will always arise: Which students should be in which groups? What individual roles need to be assigned within a group? And how should I, as a teacher, mediate learning for the various groups in my class?

Assigning Students to Groups

Most small learning groups are created with two to four students. Sometimes groups of five are effective, but usually the smaller, the better. Keeping the group size small may limit the amount of diversity you can achieve within each group. Nevertheless, try to design the groups with as much heterogeneity as possible. Students of mixed ability, gender, and ethnicity should have the opportunity to work together toward common goals, learning about one another in the process.

Allowing students to select their own groups is not recommended. Student-selected groups are often homogeneous, with males working with males, white students working with other white students, and so on (Johnson & Johnson, p. 104). Students do not then interact with a wide variety of peers, one of the goals of cooperative learning.

You may wish to gather information from the students before you design the groups. For example, you can ask each student to write down three names of people he or she would like to work with and then build groups that include at least one person of choice for each member. Groups should work together for as long as it takes for them to be successful, but at some point you will want to shuffle the groups so that each student has the opportunity to work with as many other students as possible.

Assigning Group Roles

In formal learning groups, each member usually is assigned a particular job or role. This is important not just to promote group efficiency but to make sure that every student participates fully. When everyone has a specific task essential to the problem solving at hand, each student will be a valued member of the group.

In one model of learning groups, the teacher designs the groups but the member then select a leader, who is usually the spokesperson, responsible for reporting results to the entire class. The teacher also specifies other roles to be filled, and the group selects individuals to fill them. For example, one person could be in charge of getting materials. Another member might be the recorder, writing down the group's plans as the ideas are formulated and then making the notes available to the entire group for their journals. Another student could be responsible for group clean-up, and still another might be the checker – the person who checks for understanding, asking all members what they think.

The more complex the investigation and the larger the group, the more roles may be involved. Whatever the assigned tasks for one investigation, the roles should change for the next project.

Mediating Group Learning

As the teacher, you manage and mediate the student groups. You give directions for establishing jobs and assigning the tasks, and then you facilitate the change of jobs when a new investigation begins. You can promote effective group work by monitoring how the group is function and making suggestions. Reminders to individual students such as, "Did you check with your groups?" or "What does your group thinks?" can help promote the value of the group (Johnson & Johnson, p. 102).

Different groups make difference decisions about how to proceed with investigations, and it is important to honor and value these differences. Sometimes it will even be necessary to allow an individual to go off on an investigation by himself or herself. At the same time, however, you need to coach and prompt the groups as they struggle toward problem solving. When appropriate, offer ideas, provide focus, or give specific explanations of the problem at hand.

When the investigation is complete, invite the members of each group to discuss how well they collaborated with each other. Their comments will help you evaluate the groups' effectiveness and plan for the next group activity.

As you create this model in your own classroom, you will find that small group cooperative learning is truly essential to doing science with children. You will see for yourself that the groups encourage the process of problem solving in ways that individual instruction cannot.

Questions for Your Own Reflection

When the experience you have planned for your students is over, you may want to document what went on. If you use a constructivist approach, there is always a lot to write about, because you really do not know beforehand where the lesson will go or what the children will say or do. It is the children's thinking that propels you forward. Besides active listening to the students during the lesson, it is useful to take some time afterwards to record their ideas and your own reactions to the way the lesson developed.

Here are some sample questions to ask yourself as you reflect on the lesson and write about it in your journal:

- What did the students find out in this experience? Were there any surprises?
- How did the students in each group work together? Were there any problems?
- Was the activity open-ended enough, or did each group do more or less the same thing?
- How did the students extend the investigation?
- How did the students connect this experience to their daily lives?
- Overall, what do I think the children got out of this experience?
- What do I remember most about this activity?
- Would I do it again?
- How would I plan differently the next time?

Sometimes it is useful to record comments and reflections directly on the lesson plan book itself. Keeping your plans together in a notebook is a good idea, too. Your comments and notes have important implications for how you will address the topic the next time.

If you are comfortable using a computer, it can help you not only to create your lesson plans, but also to save them and add comments later.

Helpful Hints for Planning a Science Lesson for Student Groups

- Keep in mind that an activity is not a lesson. The lesson encompasses the thinking, reflection, and personal connections that occur because the students were engaged in the activity.
- Be yourself, and be comfortable with what you and your class are doing.
- Get yourself out of the way. That is, instead of delivering lockstep instruction, do the following:
  Provide experiences.
  Observe your students as they explore.
  Gain insight into how they work together
  Listen to their ideas.
- Offer suggestions, ask questions, prompt, and coach. Prepare and plan as much as you can. Then be prepared to alter your original plan if the class's own ideas generate a new direction, one that you may not have thought of before.
- Remember that your lesson plan should guide you, not limit you.

Resources

Johnson, D.W. and Johnson, R.T. (1994). *Learning Together and Alone: Cooperative, Competitive, and Individualistic Learning,* 4th ed. Boston: Allyn and Bacon.

Exploring Inquiry Approaches to Learning

MST Learning Standard One sets the tone for all the mathematics, science, and technology standards by focusing on inquiry. It is based on the belief that such an approach is essential in enabling all children to learn. Every child's questions about a phenomenon can lead to learning. Any approach a child takes in working out a problem is worth delving into as a path toward understanding.

It's not an easy philosophy, and it takes time. A teacher who has been involved in inquiry learning for three years said, "You can't easily pass it along to another. You have to experience it, to be physically involved." Teachers find themselves in a new role as facilitator of students' learning rather than as the repository of knowledge. The new role makes different social demands and requires different social and communication skills.

As one teacher remarked, "It's not one of those things that's, 'Now say to the children. . . . There are no short cuts." Another teacher noted, "I'm a very structured person, and planning an inquiry is hard. It takes a lot of time." Teachers have to try out different ways of being together with their students in the classroom.

Still, teachers are finding it liberating to be a learner of mathematics, science, and technology along with their students. Teachers are astonished by the depth of thinking they observe when students are allowed to investigate phenomena at their own pace, to follow their own questions, and during whole group discussions, to show and to reflect on the different approaches they and their classmates have taken in investigating a problem.

Students who learn in an inquiry environment expect to be finding out things about what they want to know. Their curiosity drives learning. One teacher, new to inquiry, borrowed a container of brine shrimp and put it in the back of the classroom directing every student to write down in a class log one thing they observed. A week later the students were still observing and asking many questions about the brine shrimp. Another teacher commented, "We need to continue growing as teachers. We need to experience what the children are experiencing."

Teachers, principals, district mathematics, science, and technology supervisors, and families who are unfamiliar with the inquiry philosophy may be put off by classroom investigations they catch a glimpse of or hear about. Hearing, for example, that seventh-graders are using manipulatives and second-graders are doing mental mathematics may lead them to think that content is not being covered appropriately.

Hands-on learning is often the starting point for inquiry, but inquiry goes deeper, requiring experimentation, reasoning, and the communication and testing of explanations. Inquiry cut through the concrete-abstract opposition that pervades school thinking about younger and older learners, basic and higher content, bottom and top students. That is one reason why it is so significant that inquiry is identified explicitly in the first MST learning standards.

> Teachers need to build their own capacity to recognize the right circumstance for good inquiry and how to capitalize on it. It's about getting students to ask questions that will help them develop inquiry skills in mathematics, science, and technology. Asking why something was designed a certain way is rich in inquiry possibilities for students. It can develop the curiosity of children to ask questions and build on their existing knowledge of the world. Working with student this way is what I call 'guided inquiry,' and it can be an effective way to teach critical thinking. *Dr. Tom Liao*

Source: Dr. Sybillyn Jennings in *NYS Resource Guide for MST*

MST: Learning Built from the Inside Out

Picture this: You're sailing along calm, crystal blue seas, gazing at a powder blue sky that is dotted with wisps of white. Suddenly gusts of wind interrupt the calm. You must adjust the sails but your pulley system fails to operate. Two problems must be solved before you can reach the shore safely: how to reconfigure the pulleys and how to calculate the effort needed to handle the load. However, 42 minutes has passed, and science is quickly drifting away. Your focus must now be on math. And to make matters worse, your handbook only contains information on how to add unlike denominators. Now you're really stranded.

This fragmented, nonsensical scenario is one we as teachers expose our students to every day as they "learn" how to understand the integrated world in which they live. With this fundamental contradiction in our minds, we set out to try to build a bridge in a classroom setting that would allow our students to travel over into the real world. The vehicles in which we wanted them to ride upon were based on the blueprints of the *MST Learning Standards* and *Benchmarks for Science Literacy*. These documents specify that subjects be integrated wherever possible and emphasize hands-on involvement rather than memorization of facts.

Why utilize technology in the classroom? Again, picture a real-world scenario. The fruitlessness of learning that involves having ideas and not being able to implement them in meaningful ways can be compared to understanding the function of the heart without using this knowledge to create an artificial facsimile to benefit people. In the classroom this can be seen through the eyes of a child who wonders, "Why do I need to know this? How will I use this in my life?" One wonders, with all our well-meaning instruction, what happens to the learnings of a child who is not able to actively use what he or she has learned?

Our task was three-fold:

- to integrate math, science, language arts and social studies using technology as the building tool
- to use our third grade science curriculum as the base in which all other disciplines emerge
- to allow inquiry to be the path of learning on which the children will journey.

The idea germinated from a seed that was planted by our participation in the MSTe Project, which prepares teachers to design programs to meet the new MST Learning Standards in the classroom. The process flowered from an outgrowth of team teaching, co-developing curriculum, and following the children's path of inquiry to an unknown destination.

Habitats were the umbrella under which our other science topics of simple machines, weather, and plant and animal life sciences were explored. The stage was now set to bring in the technology component that we had learned to value during our MSTe workshops. The MST Standards have provided opportunities for teachers to extend the old "tools" of the classroom, whether they be pencil and paper, chalk and books, to new tools such as saws, drills, and C clamps. The use of these tools helps redefine the job description of the teacher, turning the classroom into a multi-dimensional learning forum. No longer are these tools symbols of unskilled labor. Placed in children's hands, tools allow them to see themselves as problem solvers and empowered learners. Design and technology become the vehicle to drive the inquiry skills and allows math problem-solvers to use what they have learned without having to turn a page in a textbook containing an isolated strategy that's disconnected to any real-life application in their lives.

Since one of our main goals was to create true problem solvers, what greater vehicle to reach this destination than to present the children with a challenge to overcome. The overarching challenge for the children was to create a habitat for an animal. From our recent experience, we realized that the design of the challenge was crucial to the problem-solving process and the learnings that evolved. Therefore, besides having a vision of integration, we had to include design constraints and performance criteria in every challenge.

In keeping with the curriculum, we decided to begin with a challenge that had come from a "curator" of a zoo/aquarium.

> "You have been chosen as the architects of a new zoo/aquarium to design a complete habitat for an animal. Your habitat must be built of wood and be a rectangular prism. It may be no longer than the size of a school desk, move on wheels no larger than 8cm, and be pulled with a handle. The building of this structure will depend on available materials in class. Each group will receive $6.00 a day and you must keep an accurate running balance as you purchase supplies."

This was our dilemma: How can we provide the children with background information to guide their learning, using inquiry based on real-life experiences? A solution was presented when one child said he got an idea for the design by looking at his wagon in his garage. The next day the wagon became a part of our classroom equipment, and we realized the impact that models could have on children's explorations into the design process. We later saw how powerful the use of models was when students made connections between systems.

"Ms. Migdol, I notice something that the wheel and pulley system have in common. They both turn on cylinder dowels. Let's turn your swivel chair upside-down and see if it also turns on a cylinder."

With integration as our vehicle and the learning standards as the momentum that drove us, the children measured and sawed, hot-glued and hammered as they made right angles and perpendicular lines with wood to create a six-faced rectangular prism no longer than the length of their desk.

"Jason, we need two 12cm pieces of wood to support that beam. This piece of wood is 24cm long, all we have to do is cut it in half. Remember when you're sawing to follow my measure line exactly because both pieces have to be equal."

As teachers, witnessing dialogue like this on a daily basis reaffirmed how design and technology integrated learnings in the classroom with real-life experiences.

Design Challenges

The performance criteria (specifications) are an integral part of any design challenge. Decisions must be made and designs planned based on a specific function, in this case, the habitat's ability to move and be pulled with a handle. The constraints on this challenge were size, shape, and the amount of money they received to purchase materials. Built into the design were constraints. Constraints and performance criteria both shape the children's thinking and decision making. Teachers can use these two integral parts of the design challenge to facilitate specific curriculum objectives. Performance criteria define function and differ from constraints in this aspect, but the importance of including both cannot be emphasized enough.

A Design and Technology Folio helped students to formulate clear plans and share information with their partners, while also serving as an important assessment tool for us as teachers. For long-term projects, a daily journal to record reflections, plans, and questions is an essential learning and assessment tool.

The Many Faces of Math as Seen Through Science and Technology

How many times have we been exposed to "integrated" projects only to find the same listing of math topics that connect to the science: measurement, data collection, graphing, geometry. How can we explore and implement other important content areas of the math curriculum through the science we teach? Using the Habitat Project we developed a schematic plan that addresses this problem.

Math presents itself in three ways through science and technology: *inherent*, *incorporated*, and *attached*. This enables a teacher to delve into a full, meaningful math curriculum.

Math Learnings *Inherent* in the Design Process

Inherent learnings involved the math that naturally supported the science and technology learnings. For example, while measuring and building the wooden frame and wheels, children experienced first-hand that right angles made the sturdiest structure and parallel lines (wooden dowel axles) were the reason why wheels could roll straight ahead. Inherent math included:

- metric measurement, estimation
- measurement tools: ruler - reading a number line
- geometry - angle formation, perpendicular, parallel lines, vertices, faces, three-dimensionally
- addition and subtraction

Math Learnings *Incorporated* in the Design Process

When the children were building, habitats of different sizes emerged. Focusing on curriculum directives, we saw a perfect opportunity to incorporate the concept of area to compare the different size bases of the habitats. Color tiles were used to explore this space and arrays were formulated. We economized our teaching time by coupling this learning experience in introducing multiplication. As the children compared the areas of their habitats, they needed to use the tools of subtraction to show the differences between the areas. In these situations, the mathematical concepts were not directly related to the understanding of the science or the building experiences, but the opportunities emerged as we observed the properties of structures or when we made comparisons. Incorporated math included:

- area and multiplication
- greater than, less than, and subtraction
- shapes - cylinders
- circle - diameter and midpoint

Math Learnings *Attached* in the Design Process

We had to create a need for the children to explore certain math concepts. By attaching values of money to the building materials, we could set the stage for the children to have an ongoing experience practicing math skills using addition and subtraction algorithms to explore money and decimals in a real-life context. When remaining topics in the curriculum need to be explored, a purpose was created and they were pushed into the
project. Attached math included:

- money: notation, addition and subtraction, decimals
- estimation

Other Areas of Integration

Science
simple machines - wheel and axle, lever

Technology
plan, design and construction
use and evaluate materials to satisfy needs

Language Arts:
Portfolio/MST journal - writing
oral communication
research skills
non-fiction reading

Our Journey had Just Begun...

This ended up being a yearlong project with many mini-challenges presented to the children. Through this process, we found all of our curriculum objectives were addressed. Listed below are some of the constructions that children included in their habitats.

- Pulley system monorail with a vehicle made out of origami to transport visitors
- Moveable scroll depicting different aspects of the culture of the native land of the animal
- Hinged overlay maps depicting geography, climate and natural resources of the region
- Topography of the region was represented to scale
- Adaptations of animals presented in pop-up books
- Scale animals were constructed
- Complete ecosystems were created and area divided into equal sections to hold shelter, prey, live vegetation, animals, and landforms
- Temperature comparison of local habitat and animal's region were recorded and graphed
- Probability spinners created based on analysis of temperature graphs
- Picture books were written and illustrated to share valued learnings of children's design and construction

Picture a Classroom . . .

Where children's ideas guide the day
and the hands on the clock
do not dictate
when learning starts and stops

Student: "When I went skiing this weekend, I noticed that the monorail operated on a pulley system. I figured out how it worked. The cable ran through a covering that was attached to the pulleys. When I came into class, I figured if I attached a straw to the piece of wood and put a string through it, it would be just like the ski lift."

Where children welcome problems
they are presented with as a challenge
that they look forward to overcoming

Student: "When things start to fall apart we try a different solution."

Where learning and connections continue
outside the classroom
and problem-solving strategies
are carried into real-life challenges

Parent: "My child saw a frog trapped in a drain pipe with a puddle of water near the frog. She immediately ran into the house to get a pencil, paper, and ruler. She proceeded to measure the diameter of the opening, then wrote the following questions down: How did the frog get in there? Why didn't the puddle evaporate? What does that tell me about when it rained last? What can I build to get the frog out?"

Where children of both genders
and all abilities redefine learning
and are valued by their peers
for their contributions

Student team members: "We now see ourselves as asking questions along with our teacher and exploring the answers on our own with her guidance. It's like our teacher is the North Star and we are the travelers. Sometimes we might need the North Star to point us in the right direction. But we won't have our teacher by our side for our whole lives. We have to learn to solve our problems on our own."

Source: Kathryn Chapman and Donna Migdol, Oceanside UFSD

Design and Problem Solving - Concepts and Procedures

Design as an Instructional Strategy

Elementary school children learn best through concrete experiences. Design activities are replete with opportunities for integrative, inquiry-based problem-solving activity that can help students construct knowledge through physical interaction with their environment. It is quite appropriate that design activities be initiated at the elementary school level where children set out to model solutions to problems that are *real to them*.

Design activities are not proposed as an instructional add-on, but rather, as a complement to teachers' instructional strategies. Design activities offer a contextual, intrinsically motivating opportunity to engage students in reflective problem solving and critical thinking.

Since design activities involve planning, modeling, testing, analysis, and presentation of results, they provide extraordinary possibilities for students to apply and synthesize their subject matter knowledge of art, language, mathematics, science, and social science. For example, in the design of a habitat for a pet, children must learn about the creature's needs for survival, its physical dimension, and its space requirements. They must choose construction materials and plan ways to build the habitat. They must observe the creature in the habitat, collect data, and use those data to revise their design. They use drawings and written descriptions in their plans and present their results to classmates. Children will ask many *why* questions; teachers can find opportunities to capture mathematical and scientific moments embedded in design problems as opportunities for just-in-time excursions into underlying mathematics and science ideas.

What is Designing?

Designing is a process people use to plan and produce a desired result. The result may be a product, process, or system that meets a specified human need or solves a particular problem. We use design principles in architecture and engineering. We also find examples of design in works of art, advertising, fashion, and product design.

Sometimes, designs come from original ideas and require creativity. Designers must use their knowledge and experience in new and different ways. An invention like contact lenses is an example. Another is a new advertisement for a product.

At other times, designs are based upon existing knowledge and ideas. For example, civil engineers use the experience they have gained over many years to design a highway system. They know that when they use particular types and amounts of concrete and steel to build roadways, the road will support certain loads safely.

Engineering Design

Engineering design is a planned method of making choices about design solutions. Engineering design exists on a continuum, from activities in which young children engage when they design structures with blocks to sophisticated science- and mathematics-based high-tech design involving a multiplicity of systems and subsystems.

The best design is the one that meets all the design requirements within all of the limits (like costs and time) that have been imposed. Normally, in solving engineering design problems there is more than one workable solution. Picking the best design out of all the possibilities invariably involves making tradeoffs. This is different from solving the kinds of mathematics problems that are usually found in school textbooks, where the problems are very well defined and there is normally only one correct answer.

Engineering problems are seldom well defined. For example, if the problem is to design a home for a family, there are many choices that the builder can make and many possible designs that would work. The problem is not well defined because numerous tradeoffs could be made relative to the size of the house, the kind of material it would be built from, the type of heating system, the costs, and the time it would take to build. In this case, the architect, the builder, and the customer would talk among themselves to clarify the design problem and discuss how to arrive at the best possible solution.

Engineering design makes use of an *iterative* method of problem solving where each idea is tried, tested, and revisited. It is a process that involves making some decisions without complete knowledge and then coming back to those decisions again later in the process. For example, when the rooms of a house are initially designed, the customers may specify that they want a large guestroom but later might decide that two smaller bedrooms would provide more flexibility in case a child is added to the family.

More and more, engineering design is becoming the job of a team. One person usually doesn't have all the knowledge necessary to develop a good design. For example, if the problem is to design a children's toy, then people with a good knowledge of manufacturing processes and people with experience in sales and marketing might be added to the design team. This process is sometimes referred to as *concurrent engineering* because different aspects of the problem are being worked on concurrently (at the same time).

Most engineering design problems also involve an *analysis* phase. After a design solution is picked, the engineer analyzes the solution to see if it really will work under all of the conditions that it will be subject to. For example, if a steel beam is being designed for a bridge, the engineer will do a structural analysis of that member. The analysis is done by using mathematics to see if the steel member will be strong enough to stand up under load. Mathematical analysis is a very important part of the engineering design process.

Design Criteria

Designers must consider how best to fulfill design requirements. Most often they have to work within given limitations. The requirements of the design (sometimes referred to as specifications or "specs") are called the design criteria. The limitations are called *constraints*.

Design criteria specify how a design is expected to *function* or *perform*. For example, design criteria for a paperweight might be that it is attractive, feels good to the touch, and can keep 30 sheets of looseleaf paper in place even when a fan is blowing. Design criteria for toothpaste might include that it cleans plaque from teeth, tastes good, and can be squeezed easily out of a tube. A design criterion for a certain type of car might be that it could accelerate from 0-60 mph in less than ten seconds.

Design criteria often include safety considerations. Stating that a passenger elevator must have a safety factor ten times greater than the load it is expected to carry or that the front of a car will not be damaged after a crash at 5 mph are criteria that the designer must meet. Design criteria can be thought of as all the *functional performance requirements* that a solution must meet.

When people design, they must take into account design criteria such as functionality, quality, safety, ergonomics (ease of use), and aesthetics (appearance).

"Functionality" refers to the ability of the product, system, or process designed to fulfill its intended purpose over its desired life span. For example, a light bulb manufactured to give 1,000 hours of service is expected to supply light for this period of time.

Safety codes and regulations must be met. The product, system, or process must be designed to be safely used by consumers. For example, cooking utensils that are made of heat-conducting materials should have handles made of materials that do not conduct heat well.

Ergonomics, also called "human factors engineering," deals with designing for ease of use by people. Ergonomics combines knowledge of the human body with the techniques of design and engineering. A good design fits the user's size and capabilities. For example, a desk chair must be designed for human comfort. An automobile dashboard must show information in such a way that a driver can read it at a glance. A computer keyboard must be suited to the size and functioning of the human hands and fingers.

When designing for people, the designer must keep in mind that people come in many sizes and shapes. There really is no average person. Most often, designers work in the middle of the range of body sizes. They neglect the bottom 5 percent and the top 5 percent of dimensions. For this reason, a pocket calculator may have buttons too small for people with very large fingers.

Designers depend upon the field of *anthropometry* for information about the size and shape of people's bodies. Anthropometry is the science of measuring people. An American designer, Henry Dreyfus, pioneered the field of anthropometry. He collected huge amounts of information about people's shapes and sizes and made up charts of the average sizes of different parts of the body. He also collected information about how much pressure a foot could apply to a pedal, how hard a hand could squeeze, and how far a leg could extend. Dreyfus put together a picture of the average man and woman and called them Joe and Josephine. He also collected data about average six-year-olds and called them Joe and Josephine junior.

Figure 1 shows body dimensions of U.S. adults. The average adult male is 68.3 inches tall. The average female is 62.9 inches tall. In other countries, people's average body dimensions are different. In Southeast Asia, for example, the average male is 64 inches tall and the average female is 60 inches tall. Companies that export such products as bathtubs and beds to other countries must take anthropometric data into account.

Aesthetics refers to the way something looks and how that affects people's feelings. Designers know that to sell a product, they must make sure people like the way it looks.

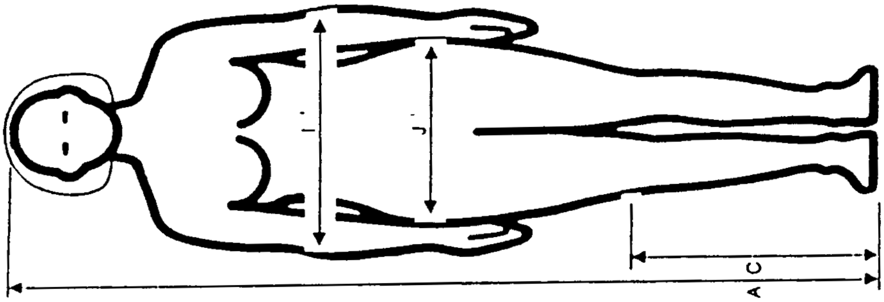
The *form* of an object is often determined by its *function*. Tables hold plates of food, so they are flat. Because drinking glasses are usually held in one hand and contain liquids, they are higher than they are wide. It would make no sense to design tables with slanting tops or drinking glasses too wide to grasp.

Design Constraints

Designers also work under certain constraints. Constraints are limits that are imposed on the designer. Constraints are often related to *resources*, such as what kind of *materials* the designer is able to use, how much *money* a finished product can cost, or how much *time* can be devoted to producing it. Other limitations can relate to the availability of workers and the effect of the design on the environment.

Figure 1. Body Dimensions of U.S. Adults

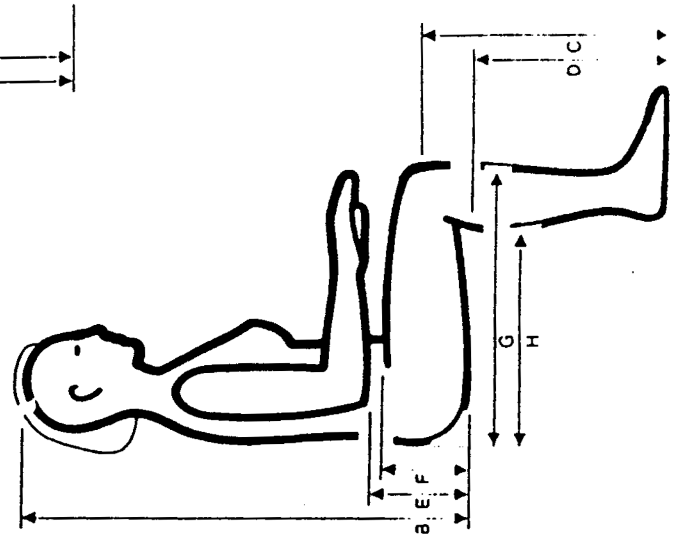
Adult Female



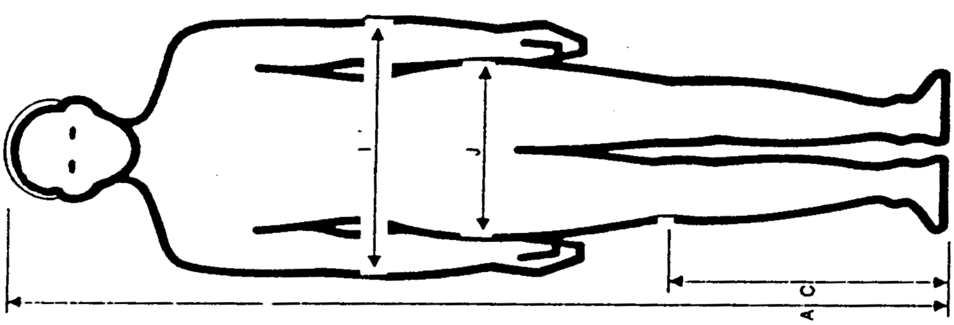
Selected Anthropometrics Features
National Health Survey of the
United States Public Health Service.

Body Feature	Female, Percentile 5th	50th	95th*
A Height, inches	59.0	62.9	67.1
B Sitting height			
- Erect	30.9	33.4	35.7
- Normal	29.6	32.3	34.7
C Knee height	17.9	19.6	21.5
D Popliteal height	14.0	15.7	17.5
E Elbow-rest height	7.1	9.2	11.0
F Thigh-clearance	4.1	5.4	6.9
G Buttock-knee length	20.4	22.4	24.6
H Buttock-popliteal length	17.0	18.9	21.0
I Elbow-to-elbow breadth	12.3	15.1	19.3
J Seat breadth	12.3	14.3	17.1
- Weight, pounds	104	137	199

*5th percentile: 5% of the population have smaller dimensions.
50th percentile: 50% of the population have larger dimensions and 50% smaller dimensions.
95th percentile: 5% of the population have larger dimensions.



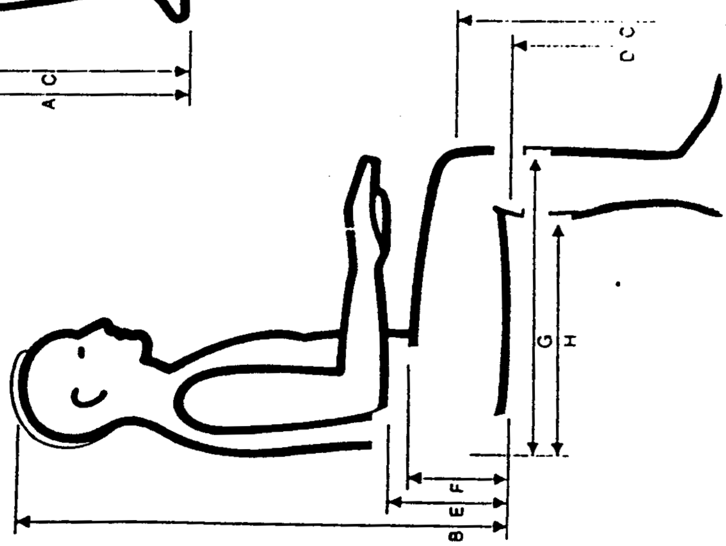
Adult Male



Selected Anthropometrics Features
National Health Survey of the
United States Public Health Service.

Body Feature	Male, Percentile 5th	50th	95th*
A Height, inches	63.6	68.3	72.8
B Sitting height			
- Erect	33.2	35.7	38.0
- Normal	31.6	34.1	36.6
C Knee height	19.3	21.4	23.4
D Popliteal height	15.5	17.3	19.3
E Elbow-rest height	7.4	9.5	11.6
F Thigh-clearance	4.3	5.7	6.9
G Buttock-knee length	21.3	23.3	25.2
H Buttock-popliteal length	17.3	19.5	21.6
I Elbow-to-elbow breadth	13.7	16.5	19.9
J Seat breadth	12.2	14.0	15.9
- Weight, pounds	126	166	217

*5th percentile: 5% of the population have smaller dimensions.
50th percentile: 50% of the population have larger dimensions and 50% smaller dimensions.
95th percentile: 5% of the population have larger dimensions.



Source: National Health Survey of the United States Public Health Service

Constraints of time and cost are often imposed on the designer by customers. For example, when an architect is hired to design a new bathroom in a house or apartment, the job usually has to be done for a specified amount of money and within a certain amount of time.

The Conduct of Design-Based Problem Solving

When children are seeking solutions to a design problem, trial-and-error problem solving often drives their search. Although trial and error may lead to an effective solution, their activity is often random, unplanned, and wasteful of time and materials. A planned process involving a series of steps helps students to find effective solutions and improves economy of resources.

There is interplay between inquiry and design. Design activities can serve a stimulus to inquiry. Once children are engaged in the search for a solution, they become invested in the solution's performance. Thinking about the factors that affect performance can lead children to ask *why questions,* which lead to inquiry into the behavior of variables. Likewise, science investigations can stimulate design, particularly the design of models that help explain a concept or of a tool or instrument that facilities data collection or experimentation.

Problem solving is rarely a linear process. Designers and engineers often bounce back and forth from one process to another. However there is a generally agreed upon set of steps generic to effective technological problem solving. Here is problem-solving procedure that has seven steps:

1. Describe the problem clearly and fully.
2. Identify the design criteria and the constraints.
3. Gather information from research.
4. Generate alternative ideas.
5. Choose the best solution and improve it.
6. Implement the solution you have chosen.
7. Evaluate the solution and make necessary changes.

As work proceeds in solving a design problem, it is a good idea to suggest that students keep a record of all design ideas, drawings and the information collected in a design activity portfolio, such as the one included in this Guide. The portfolio can be used to document the work and thought that went into the solution. It should have a separate section for each of the steps in the design process. The portfolio can be used for reference in case changes are to be made or to help produce a similar project at a later time. It can also be shown to other students and parents.

Step 1: Describe the Problem Clearly and Fully

To solve a problem, we must first understand it. Think about the situation that caused the problem and requires us to think about finding a solution. A statement describing the problem provides a way of thinking clearly about it. Here are some examples of well stated problems:

- People with arthritis in their fingers have a hard time gripping small objects. They need an easy way to carry out such tasks as unlocking a door.
- Colored drawing pencils spread out on a desk roll off easily and break, but hunting for the right color pencil in the box is a nuisance.

Once we know what the problem is, we can decide what to do about it. We might decide that the problem is just too big for us. It will have to wait until a group of people with enough money and time get interested in solving it. Or we might decide that the problem is uninteresting or unimportant and we don't want to work on it at all.

Most of the time, we need to solve problems that are presented to us. Sometimes we want to solve them because the solutions are important to us. Sometimes we have to solve them because parents, teachers, or friends ask us to. Sometimes we want to solve problems because they are challenging and we think it will be fun to come up with a solution.

Step 2: Identify the Design Criteria and the Constraints

Once the problem is understood, the student can specify how the design is expected to perform (the design criteria) and the limitations that must be considered (the constraints).

Sometimes other constraints exist beside those specified in the problem. Sometimes these constraints might be imposed by the teacher or by a specific working situation. It is important all the constraints are recognized before beginning the actual design activity.

Step 3: Gather Information from Research

An important part of solving any problem is collecting information about it. Two kinds of research are generally done when solving design problems. The first kind is *general research*. By knowing how other people have approached similar problems, effective and ineffective solutions become apparent. Information can be gathered from other people, from library research, or through electronic media.

The second kind of research is *math and science research,* which includes making measurements, collecting data about materials and the performance of the design, and rating various alternatives against one another.

Scientific investigation can inform the design solution. Conducting experiments helps to determine how certain choices of variables affect the performance of the design. During these investigations, the designer carefully observes the effect of one thing on another. For example, to design an ice chest for camping trips, an experiment might be set up to determine the effectiveness of different materials in keeping things cold. The results of this investigation would be used to help make design decisions about the ice chest.

Companies also do *market research* to determine if customers will like a new product. Sometimes companies ask potential buyers to fill out a questionnaire to find out what they like or don't like. For example, if a company wants to develop a new toothpaste for children, the questionnaire might ask a sample of elementary school students their opinion on the toothpaste they're using now. Do they like the taste? Do they like the way it feels in their mouths? What kind of dispenser do they prefer to use, a tube or a pump? What colors do they prefer for the toothpaste and the packaging? The company will use the results of this research to design the product so it appeals to the greatest number of people.

Step 4: Generate Alternative Ideas

The research done in Step 3 may give one or more possible ideas for solutions to the problem. The ideas can be totally different, or they can be improvements to the first idea. There is almost always more than one solution to every problem, and good designers are rarely satisfied with the first idea that pops into their minds.

Developing new alternatives is one of the most important parts of the problem-solving process. How do we come up with them?

One way to develop alternative solutions is to use our *past experience*. When we do research, our information comes from the past experiences of others; by using our own experience and thinking of how we might have solved similar problems in the past, we may find a new way to solve the problem.

Another way of coming up with alternatives is through *brainstorming*. During brainstorming, each person in a group can suggest ideas. One person writes all the ideas down; no one is allowed to laugh at or criticize an idea, no matter how foolish or unusual it might seem.

The brainstorming process is used to help people think more creatively. People feel free to share any wild ideas they may have. Sometimes one person's wild idea will open up someone else's mind to a totally new approach. After many ideas have been proposed, the group reviews them all. The best ideas are then developed further.

A third way to develop alternatives is by *trial and error*. This is the way most people do jigsaw puzzles. When putting together a puzzle, we are really solving a problem by trying out different ways of placing the pieces. Eventually, all the pieces are put in the correct places, and the problem is solved. When solving real problems by trial and error, the end result may not fit together as perfectly as a completed jigsaw puzzle, but the process used to solve it is similar.

A fourth way to develop alternatives is to use what psychologists call *insight*. Have you ever had an idea just pop into your head? These sudden ideas are usually followed by the "Aha!" response ("Aha! I've got it!"). Insight comes from being thorough in researching the problem and from being creative in thinking about the problem from many different angles. Even when we are not consciously thinking about the problem, our brains may still by working on it.

Still another way alternative solutions are discovered is by *accident*. Some of the most important discoveries, like penicillin, occur when the inventor goes as far as possible and still doesn't solve the problem. A chance happening then provides the answer. In other cases, the solution to a problem is discovered by someone who is looking for the solution to another problem. It takes insight to recognize when a solution has been discovered by accident.

Some students are visual thinkers and might be encouraged to draw their alternative designs. More tactile learners might be encouraged to create 3-dimensional models even before attempting to make drawings. It should be noted that an approach which rigorously insists that children draw first and only then construct a model might disenfranchise those whose drawing skills are not yet developed.

Step 5: Choose the Best Solution and Improve It

Once a list of alternative solutions to the problem is developed, each alternative must be examined to see if it meets the design criteria and constraints. The alternatives are rated to see which is best by listing the strengths and weaknesses in relation to the design criteria and constraints.

To make decisions, it might be necessary to do more research by testing each alternative and gathering data about its performance. The results of these tests are recorded and compared with the results from other tests so that a fair and accurate decision can be made about which solution is best.

Sometimes, the testing will suggest that if we change one alternative slightly or combine two or more alternatives, we will wind up with a better solution. These improvements to the design can lead to better performance, increased safety, and/or lower cost. The process of improving each alternative, or improving each part of a design, is called *optimization***.**

Often, various alternatives may be better in different ways. For example, one material may be stronger but a second material may cost less. When we choose the best solution, we normally make *tradeoffs*. That is, we give up one desirable thing for another. In such cases, we must decide which criteria are the most important and arrive at the best overall solution to the problem. The process of making tradeoffs leads to the best compromise.

By optimizing the alternatives and then making tradeoffs, we can arrive at the best possible solution to the problem. The idea is to wind up with a design that best meets the criteria, fits within the constraints, and has the least number of negative characteristics.

Step 6: Implement the Chosen Solution

Once the best solution is chosen, it can be tried out. This step is often called *implementation*. Implementation means actually building or creating the proposed solution.

Most often a model of the solution is made first. This is particularly important if the proposed solution is very large and costly, or if many of the final products must be made, or if the proposed solution presents risks to people or the environment. For example, a model of a nuclear power plant would be built and debugged before the actual power plant was built.

A model can be full sized or it can be a smaller scale (or even a larger scale) version of the proposed solution to the problem. For example, a small scale model of a new airplane would be built to test in a wind tunnel before the first actual plane was built. A large scale model of a tiny integrated circuit might be built so that all the parts and connections could be seen clearly. Skilled craftspeople and technicians are often employed to make models before full scale construction or production is started.

Step 7: Evaluate the Solution and Make Necessary Changes

Once a model of the solution is built, it can be studied and tested to see how well it satisfies the design criteria and fits within the constraints. Observing (monitoring) the results of the tests may suggest how to improve the design or construction of the solution. The feedback will allow us to compare the actual results with the desired results and assist in determining the changes to be made.

In industry, once the model meets the design criteria, the design is *scaled up*. Scaling up the model means building it the way it actually would be used. If the small scale model of the airplane that was tested in the wind tunnel proved to be a good design, a full size plane would then be built. The first scaled-up design is called the *prototype*. The prototype is tested and evaluated under conditions of actual use.

After any needed changes are made to the prototype, production of the full-scale design can begin. Perhaps a large building will be actually built or a product will be mass-produced. Evaluation must be a continuing process. Feedback should be obtained and used over the life of the product or solution to make sure that it continues to meet the design criteria. If necessary, additional changes are made to the product during its life.

Presenting Ideas to an Audience

After a design is finished, oral and graphic language skills can be learned and reinforced through presentation of results. In the real world, results are often presented to sell clients on the idea that the design is worth producing. Presentations are also made to potential users of the designed product in the hope that they may become customers. During the presentation phase, students should be encouraged to explain:

- the questions they addressed
- the research they did
- the alternatives they considered
- the rationale for their solution
- any tradeoffs they made
- how they tested their solution
- the results of their tests
- what they might do differently next time.

Various graphic techniques are used to make the presentation of results more interesting, including graphs, tables, or charts. Graphs are often used to show how something changes over a period of time. Tables and charts are used to organize and clearly display information.

In presenting results, encourage students to try to use several different media. In addition to tables, charts and graphs, other possibilities include the use of computer-generated and hand-made drawings, photographs, slides, overhead transparencies, video, or audio. Even if a design idea is a good one, presenting it ineffectively may leave the audience unconvinced.