N Y S C A T E

pedagogical FRAMEWORK

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NEW YORK STATE CURRICULUM
for Advanced Technology Education

Integrated MST Design Activities for
High School and Community College Students

Partners in New York State Curriculum for Advanced Technology Education

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

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NYSCATE Website:

www.nyscate.net

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WHAT NYSCATE IS: AN INTRODUCTION

The New York State Curriculum for Advanced Technology Education (NYSCATE) has been developed by a consortium of two-year and four-year institutions (Finger Lakes Community College, Fulton Montgomery Community College, New York City Technical College, and Hofstra University) in cooperation with the New York State Education Department. NYSCATE has developed, field-tested, and prepared for distribution 13 grades 9 - 14 advanced technological education curriculum modules. The modules represent three areas of technology (bio/chemical, information, and physical). Each module features the integration of mathematics and science principles through informed design. At the instructional core of NYSCATE materials is the use of informed design as a strategy to integrate mathematics and science principles with technical content. The modules integrate academic and career and technical education and target a variety of courses: Regents sciences, tech prep, and technology education.

USE OF THE NYSCATE PEDAGOGICAL FRAMEWORK

The *Pedagogical Framework*'s main target audience is you and other teachers who are using or want to use one or more of the NYSCATE modules in your teaching. The framework consists of 14 topics of interest to educators and three appendices. The intent is to provide scaffolding that will help you proceed pedagogically in new ways. For instance, every NYSCATE module features an Informed Design Challenge that students are expected to address through the application of science, mathematics, and technology principles rather than through trial and error. You may want to use this document to update yourself through topic 2, Design Challenges, or on other NYSCATE topics such as topic 3, Knowledge and Skill Builders. The Table of Contents will help you to locate the 14 topics and the appendices.

TOPICS FOR EDUCATORS

1. Identifying NYSCATE Modules for Your Program

One- to two-page descriptions of each of the NYSCATE modules are available for preliminary consideration (see Appendix 1). Complete modules are available by downloading from the NYSCATE Website www.nyscate.net, or by requesting hard copy from Lois Miceli, 133 Hofstra University, Weed Hall, Room 209, Hempstead, NY 11549-1330 (516) 463-6482, soelmm@hofstra.edu.

2. Understanding "Informed Design Challenges"

Obtain a NYSCATE module such as *Drying by Design* (see Appendix 3), and examine the Introduction and Overview section. In the same section, examine the Setting the Context subsection, paying particular attention to "Design Challenge."

3. Relating Knowledge and Skill Builders to the Design Challenge

The second phase of the informed design process is labeled "Research and Investigation." It is during this phase that students are asked to suspend their tendency to immediately begin work on the Design Challenge and instead take some time to "inform" themselves about the problem, and to develop the knowledge and skills that will be useful in meeting the challenge. Some of the investigation of the topic might be planned and carried out by the design teams on their own. The module also provides targeted help in the form of Knowledge and Skill Builders (KSBs). Here are some steps toward seeing the relationships between KSBs and the Design Challenge:

- Once you are familiar with the Introduction and Overview section of a NYSCATE module (such as *Drying by Design*), turn to the Timeline Chart section and skim the timeline for the module. Note that students do not begin to address the challenge until they have completed a series of Knowledge and Skill Builders (KSBs) for that module.
- To ensure that key ideas in mathematics, science, and technology are explicit components of each learning experience, you should engage your students in these Knowledge and Skill Builders. The KSBs are short, carefully developed, focused activities designed to teach salient mathematics, science, and technology processes, skills, and concepts and provide the necessary foundation for more open-ended design activity. The KSBs are designed to enhance students' understandings and skills, thus enabling them to develop better informed design solutions. The KSBs can serve as one of the bases for your assessment of student progress.
- To see what a KSB consists of, turn to a module such as *Drying by Design*. In Student Packet 1 of that module examine the student KSB called "KSB T1: The Design Cycle," paying particular attention to the informed design loop figure. Select a mathematics KSB (KSB M) or a science KSB (KSB S) from this module and examine it also.

4. Using the FOCUS Pedagogical Model

In recent years, there has been growing recognition of the educational value of design projects, through which students design and create external artifacts they can share and discuss with others. All too often design, as an instructional strategy, has not been used to advantage; the focus has been on the designed product rather than on learning from the experience. As a pedagogical strategy, design activities can be very powerful. They have the potential to:

- engage students as active participants, giving them a greater sense of control over (and personal involvement in) the learning process;
- assist students as they integrate learning from language, the arts, mathematics, and science;
- encourage pluralistic thinking, avoiding the right/wrong dichotomy prevalent in most math and science activities, and suggesting instead that multiple strategies and solutions are possible;
- provide a context for reflection. Students' constructions serve as external shadows of their internal mental models, providing them with an opportunity to reflect upon, and then revise and extend, their internal models of the world;
- encourage students to put themselves in the minds of others, since they need to think through how other people will understand and use their constructions (Resnick, Mitchel. *Technologies for Lifelong Kindergarten*. Educational Technology Research & Development [1998]).

There are different ways for you to facilitate design tasks. One way that promotes integrated learning is to use the NYSCATE FOCUS model presented below. This model emphasizes the importance of focusing students early and keeping them productively engaged in learning throughout the informed design process.

THE NYSCATE FOCUS on Informed Design: A Pedagogical Strategy for Teachers

FOCUS is a pedagogical model that is intended to concentrate your attention on a small set of roles that are central in teaching students to employ an *informed design* process in meeting a "Design Challenge." FOCUS is an acronym that serves well in ordering, emphasizing, and helping to remember these important teacher roles. The order in which the roles are presented in the model approximates the order in which they dominate as you proceed through the instructional process. As a complement to the FOCUS model for teachers, a model of informed design has been developed to provide scaffolding to students as they undertake design solutions.

Focus
Organize
Coordinate
Unite
Sum Up

Focus Students on the Problem Context Initially, you have to FOCUS and engage the attention of students.

- Presenting a practical problem-solving context with which students can identify serves this purpose. The context directs attention to a human need, which might be addressed through designing a product or method for doing something.
- The task for the student is formulated as a Design Challenge.
- The challenge includes the specifications for what is to be accomplished and the constraints under which the work is to be done. Students should be made aware of the resources they will and will not have available and how long they will have to work.
- At this point, you should present and discuss the Design Challenge with students, until you have made clear what is being asked of them.

Organize for Informed Design Once the students understand the challenge, your FOCUS should shift to getting students started on an organized path. At this point, momentum can easily be lost if you do not provide sufficient structure based on the students' prior experience with the informed design process.
You should:

- Introduce or review the phases of the informed design process, contrasting the more formal and planned approach of "informed" design with the everyday, spontaneous approach to design with which students may be familiar.
- Form design teams and set the ground rules for team interactions.
- Inform students of the type of record keeping to be used: logbook or Design Journal (DJ), lab book or Design Folio (DF). Emphasis should be placed on keeping complete and accurate records of individual thinking, actions, and results.
- Specify how student assessment will be accomplished, including what will be graded and the criteria and standards to be used.
- Students sometimes have developed a natural familiarity with and affinity for designing. Unfortunately, they often seem to prefer trial-and-error methods. To overcome this tendency, you should establish the expectation that science and mathematics principles are to be applied to the problem solution.

Coordinate Student Progress Once the work of design teams has been launched, you should FOCUS on coordinating the effort and facilitating what teams and individuals are trying to accomplish as they proceed through the informed design process.

- Teams will need time, physical resources, knowledge and skills, and encouragement along the way, all of which you can help to provide.
- Resource management can be one of your most time-consuming responsibilities. Students must have access to materials, equipment, and working space when they need it if they are to gather data on factors influencing solutions, build prototypes, and test ideas.

Focus
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- Your timely introduction of the Knowledge and Skill Builders (KSBs) provided in the module can be an especially important facilitative role.
- After the design teams have made some progress, you should gather the class together so that teams can share tentative solutions and problems.
- Continually monitoring individual student roles and contributions to their team effort as well as conducting checks of students' individual written records is an essential task if you are to keep these student responsibilities from becoming a problem.
- You may have to give special attention to females and underrepresented minorities to encourage them to participate in this type of task, which some may feel does not draw upon their strengths. The fact that students are working in teams must not distract from your responsibility to help each student learn.
- Conveying a general sense that you enjoy student interchanges and feel that they are important can encourage students to respond in positive ways and remain engaged.

Unite the Class in Thinking about What Has Been Accomplished As the teams' efforts to meet the challenge draw to a close, your FOCUS should shift to uniting the class once again to reflect on and learn from the accomplishments of each other.

- Each student can benefit from seeing the strengths and weaknesses in both the process and products of others' work and from having their own work critiqued in a supportive environment.
- To realize these benefits, students need an opportunity and sufficient class time to present their work in a formal way. If time permits, both a design team presentation and an individual written Design Report can be prepared. For purposes of NYSCATE pilot- and field-testing, both the reports and the presentations are requirements for students. (The design presentation may be oral or in the form of a poster display.) If these efforts will be graded, students should be informed ahead of time of the criteria to be used.
- You may wish to shape this assignment so that it provides an opportunity 1) for students to produce high-quality, on-time work, 2) for all students to apply their language arts skills, and, for those with limited skill in technology but special strengths in language arts, a chance to contribute, 3) for students to learn to use writing and presentation technology, 4) for students to realize the importance of good record keeping, 5) for student self-reflection on abilities, knowledge, work habits, and motivation, 6) for representation of work forms that can be graded, and 7) for preserving students' best work for use in an academic portfolio.

Sum Up Progress on the Learning Goals Your final FOCUS must be on summing up progress toward meeting the learning goals. Both the individual students and the effectiveness of instruction should be evaluated.

- You should keep in mind that the design challenge is a means to an end in accomplishing the learning goals. Reviewing the module's learning goals periodically can help you stay on track during the module and during its assessment.
- Holistic experiences such as working on Design Challenges can have many benefits. Improvements may be seen not only in abilities but also in conceptual understandings in technology, mathematics, science, language arts, and general problem solving. The grading system could capture any of these improvements.
- For your assessment of students, the goal is to be constructive. Emphasizing student progress and identifying specific areas for improvement are recommended. Several tools for this purpose are supplied with the module or in the *Pedagogical Framework*: these include process-rating forms, content tests, and preliminary product-scoring rubrics.
- Ultimately, you have to combine the various methods of assessment to arrive at a grade that is consistent with the methods of grading you presented to students during the organizing phase of the module.
- Knowledge of student progress on learning goals can contribute to a general evaluation of the module and the instruction used. This evaluation should be completed to guide improvements for the next time. Keeping teaching notes or a journal during the use of the module can be very helpful in this process.

5. Using the NYSCATE Model for Informed Design by Students

Technological design is a planned process of making design choices and trade-offs within given constraints, which leads to the development of a product, process, or system that satisfies human needs or wants. Technological design is a multidisciplinary problem-solving process involving the synthesis of many areas of knowledge and skills including technical, scientific, mathematical, societal, ethical, environmental, aesthetic, and linguistic.

Typically, school problems are well defined; that is, given this, find that. Students have become accustomed to narrowly focused problems. A typical mathematics problem is: If a train leaves the station at noon and arrives at a town 200 km away at 4:00 p.m., at what average speed must it travel?

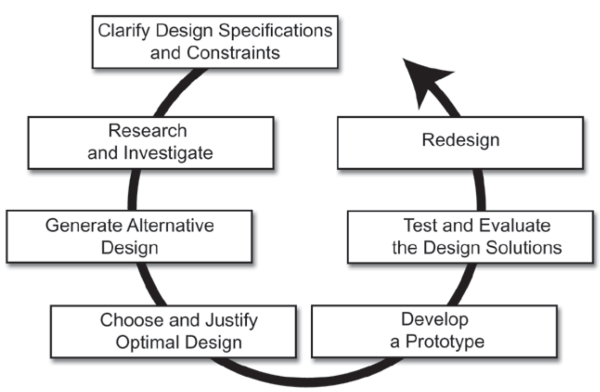
Design problems are seldom well defined when first encountered. For example, if the problem involves the design of a home, many choices, decisions, and trade-offs have to be made before the design solution can be realized. Decisions must be made regarding heating and insulation cost, shapes and sizes of rooms, placement of the house on the lot, and features of the house in relation to total cost. The architect, contractor, and client should meet to clarify the problem and discuss solutions. Knowledge drawn from several fields must be integrated into the design solution. An understanding of climate control, building construction, cost analysis, legal procedures, and interior design all shape the design of the home. The design process begins with broad ideas and concepts and continues toward the refinement of details.

The design process is by nature iterative, since some decisions are made hastily and therefore must be revisited. Each element of a solution can be refined in a multi-step process involving monitoring performance against desired results and making appropriate modifications. Typically, trade-offs are required to address design criteria optimally.

NYSCATE uses a particular method (see informed design loop) in each module to seek informed technological design from students.

The loop includes several phases that together are referred to as the design cycle. These repeatable phases engage the student in the design process. The student works in a manner similar to that of professional engineers. Engineers and other designers rarely follow these phases in order. Instead, they move back and forth from one phase to another as needed. You also should not expect students to go through these phases in the same order each time they design something. The designer arrives at solutions while monitoring performance against desired results and making appropriate changes as needed. Almost always, following design criteria leads to trade-offs taking place. The phases of the informed design cycle are described here:

NYSCATE Informed Design Loop



Phase 1: Clarify design specifications and constraints. Describe the problem clearly and fully, noting constraints and specifications. Constraints are limits imposed upon the solution. Specifications are the performance requirements the solution must meet.

Phase 2: Research and investigate the problem. Search for and discuss solutions that presently exist to solve this or similar problems. Identify problems, issues, and questions that relate to addressing this Design Challenge.

Phase 3: Generate alternative designs. Don't stop when you have one solution that might work. Continue by approaching the challenge in new ways. Describe the alternative solutions you develop.

Phase 4: Choose and justify optimal design. Defend your selection of an alternative solution: Why is it the optimal choice? Use engineering, mathematical, and scientific data and employ analysis techniques to justify why the proposed solution is the best one for addressing the design specifications. This chosen alternative will guide your preliminary design.

Phase 4 involves: (a) hypothesizing that the design solution will meet specifications and constraints; and (b) showing that the design should work by conducting M/S/E/T analyses. When choosing the optimal design from among alternatives, two factors are in play: The first is that the optimal design is chosen by rating it against design specifications and constraints. After doing so, the designer is not yet really sure that the design will work as intended. It's not until mathematical or engineering analysis has been done that the designer is reasonably certain that the design will meet specifications. For example, if the design is a table, it is analyzed under the intended load (a stress analysis is carried out). This addition deviates from the current design models in that the addition calls specifically for two kinds of analyses: one qualitative, one quantitative. It draws the student that much closer to informed design.

Phase 5: Develop a prototype. Make a model of the solution. Identify possible modifications that would lead to refinement of the design, and make these modifications.

Phase 6: Test and evaluate the design solution. Develop a test to assess the performance of the design solution. Test the design solution, collect performance data, and analyze the data to show how well the design satisfies constraints and specifications.

Phase 7: Redesign the solution with modifications. In the redesign phase, critically examine your design and note how other students' designs perform to see where improvements can be made. Identify the variables that affect performance and determine which science concepts underlie these variables. Indicate how you will use science concepts and mathematical modeling to further enhance the performance of your design.

6. Forming and Facilitating Design Teams

Overview. Cooperative learning is a method of learning in which students are formally organized into groups of two or more (preferably three) for the purpose of working toward common goals. You may use cooperative learning as an occasional change of format or as a main organizing scheme for day-to-day, year-round instruction. While NYSCATE modules do not presuppose the steady use of cooperative learning, most NYSCATE activities are designed around the idea of students working together in teams; as a result, you may find maintenance of a team approach during an entire module a useful strategy. A common misconception about cooperative learning techniques is that they stand in opposition to individualized and competitive strategies. Instead, all cooperative learning techniques emphasize individual accountability. Additionally, group work can be competitive or noncompetitive, depending upon the cooperative learning technique used. Cooperative learning involves more than putting students in groups with a common task.

General characteristics. Most cooperative learning methods share the following general characteristics:

- Classes are divided into small groups of two to six members.
- Accountability is necessary.
- Clearly defined objectives are specified for the groups.
- A cooperative environment and a reward system are present within the group.
- Students support each other's efforts to achieve.
- There are both teacher monitoring and group monitoring of group member behaviors.

Differences. Major differences among the various methods of cooperative learning lie in the areas of:

- grouping students (Should students be grouped heterogeneously or homogeneously?)
- kinds of incentives/rewards offered to groups and/or group members (Should incentives be criterion referenced or competitive?)
- organization of the groups (Are groups formed with one-on-one peer tutoring in mind or large group interaction?)
- learning tasks (Are tasks appropriate for the cooperative learning method used?)
- expected goals (Is emphasis on achievement of content mastery or development of group social process skills?)
- specialization of tasks (How specialized and/or individualized should tasks be?)

Research. Research studies have documented the following positive effects of cooperative learning techniques:

- increased academic achievement (including depth and retention of knowledge) and peer norms that favor academics, especially for ethnic minorities and female students whose learning styles and strong interpersonal intelligence may favor group interaction over individual competition;
- improved intergroup relations; the "all for one, one for all" attitude of teamwork encourages more than superficial interactions between different racial groups and the acceptance of mainstreamed students;
- enhanced self-esteem and heightened sense of being in control;
- positive attitudes toward subject matter and learning;
- enhanced social skills and collaborative competencies;
- development of higher level, critical thinking skills.

Tasks to perform. Some teachers believe that widespread use of cooperative learning techniques will leave nothing for the teacher to do. Nothing could be further from the truth. The researchers working in this area of instructional practice believe that the teacher has a number of clearly defined tasks to perform, including:

- making decisions about the general directions and specific cognitive and collaborative skills objectives for the class;
- creating the setting and proper environment for cooperative learning to take place (you may accomplish this with prior whole class instruction; development

of worksheets and quizzes; placement of students in groups; physical arrangement of room; and explanation of the academic task and criteria for success);

- helping individual students adapt to their new roles and responsibilities;
- monitoring student groups as they work, in order to ensure task completion and also to document evidence of learning and problems that students are confronting;
- evaluating and facilitating ongoing group self-evaluations;
- providing ongoing materials and resource support for groups as they expand their research and activities.

The right climate. Building the right climate for groups to function effectively takes hard work and practice. David and Roger Johnson suggest that the following five elements be a part of each lesson:

- Positive interdependence (Make sure students know they are responsible for their own and each other's learning.)
- Face-to-face interaction (Allow students opportunities to explain things to each other and to help one another.)
- Individual accountability (Require each student to demonstrate mastery of the assignment rather than allowing one member of the group to demonstrate learning for all.)
- Social skills (Find creative ways to build trust, resolve conflict, improve communication, and encourage student leadership.)
- Group processing (Monitor group progress periodically and devote time to improving group functioning.)

Group dynamics. The complexities of behavior within groups affect everything the group accomplishes. Individuals within groups play various social roles. Social interaction among the group members and the knowledge construction that results take time to develop. Therefore, permit students to remain in the same group throughout an activity, unless a compelling instructional reason exists for doing otherwise.

Group work in school often fails to maximize the dynamics of a group because group processes are ignored. Long-term group decision making that stretches beyond one or two class periods will likely result in better group work and better decisions as group cohesiveness and natural dynamics unfold. Great attention to building relationships within groups, which requires time, results in more effective group functioning. Or as Henry Ford put it, "Coming together is a beginning, staying together is progress, working together is success."

Pitfalls. This overview of cooperative learning techniques would be incomplete without an acknowledgment of some of the possible pitfalls. Cooperative learning techniques, *if not properly employed:*

- allow for social loafing in which some group members do most or all of the work while others go along for a free ride;
- create a diffusion of responsibility with no one feeling responsible for the whole;
- are hindered by classroom management problems in the early phase of implementation before both you and your students begin to learn your new roles;
- shift too much attention to affective measures and social skill, to the detriment of cognitive objectives;
- become "the answer" and are therefore overused to the exclusion of other techniques and instructional variety.

MST connections. The NYSCATE staff members believe that certain aspects of MST issues naturally lend themselves to cooperative learning techniques due to their:

- tie to fundamental principles that may be poorly understood by the student, and therefore in need of cognitive elaboration and restructuring in a social setting,
- multifaceted, interdisciplinary nature, which suggests combining teaming and task specialization,
- controversial nature, which calls for multiple viewpoints and consensus-type solutions, and
- societal implications. Creative cognitive conflict and controversy are inevitable when dealing with MST issues.

Most educational researchers believe that using cooperative learning methods to explore controversial issues can be highly beneficial to students rather than harmful or destructive.

7. Managing the Classroom/Laboratory—Some Suggestions

Here are suggestions to help you manage materials, tools, equipment, and classroom/laboratory space efficiently and safely:

Ordering. Ensure that computer hardware and software, student materials, supplies, textbooks, and teacher materials have been ordered well in advance of projected use. Typically, materials for the academic year should be ordered by the previous May. Be sure to follow local institutional guidelines for ordering. Stay within budget allocations and know how those allocations fit into categories (capital equipment, expendable supplies, textbooks, etc.). Sometimes materials and equipment must be ordered from an approved list of vendors. Note that as a rule several vendors are given the chance to provide competing bids, and the purchaser is obligated to order from the vendor quoting the lowest price unless sufficient justification is given for acceptance of a higher bid.

Storage. Storage materials and tools should be stored in locked cabinets and tool panels. Tools should be displayed in tool holders that permit easy accessibility. Keep only those materials needed for current use in the classroom area. Other materials should be kept in external storage areas. An external storage area of 250 square feet is appropriate to supplement classroom/laboratory instructional space.

Cleanup. Develop a management plan for cleaning up the classroom and/or laboratory after each class activity period. Assign each student particular responsibilities so that five minutes before the end of the class session, attention is directed to restoring the computers and monitors, instrumentation, tabletops, floors, sinks, tool panels, power equipment, and storage cabinets to the condition they were in prior to use.

Facility planning and setup. The facility itself should be thoughtfully designed with curricular and instructional needs in mind. Work spaces (tables or benches), equipment, and utilities must be designed to address instructional needs. Typically, classrooms assigned to programs underpinned by inquiry- and design-based learning should be modified to include work surfaces suitable for team-based collaboration. When space is available, laboratories can include separate instructional and work areas. Otherwise, an integrated space using worktables alone may be designed to accommodate student seating during teacher or peer presentations. Ample space should be provided for safe student movement. In a laboratory setting, a rule of thumb is that 75 square feet should be provided for each student (exclusive of storage areas). For a class of 24 students, a recommended facility size is 1,800 square feet. Thought should be given to how seating would best be configured to allow group interaction during discussion. Movable tables and chairs provide flexibility and may be reconfigured as needed. Certain equipment (e.g., tabletop milling machine, drill press) should be mounted on unmovable surfaces (on the floor, or on tables bolted to the floor). OSHA guidelines should be followed in all cases.

8. Keeping Track of Design Work—Journal or Folio?

Students maintain a Design Journal or a Design Folio in which they include plans, document progress, and record findings. You may assign one or the other or both, or work with student teams to help them choose a method for documenting their work.

DESIGN JOURNAL

The Design Journal, a notebook maintained by each student, is a record of that student's daily progress. Research findings, sketches, ideas for construction, notes, and questions to be resolved should be included. Entries are made on a routine basis, documenting student work. The journal also contains data and observation/data analyses.

The Design Journal is an important and permanent record of student work. Use of the Design Journal consciously mirrors the documenting procedures for engineers, technicians, and scientists, all of whom maintain a journal recording their daily work. A professional journal can become an official document in the eyes of courts should patents arise from the work or if litigation regarding a project ensues. The journal contains technical matters: designs, experiments, procedures, data, calculations, and conclusions. It serves as a summary of work accomplished and may include meeting results or a log of telephone calls to clients. It can serve as a means to refresh memory should questions arise about when something was done or not done.

The journal should be signed daily, and dated, by the author. Often companies require that another person provide a signature as a witness as well. The journal itself is bound, typically consisting of a black-and-white sewn notebook, and a pen is used for making entries. The entries do not have to be perfect, but they should be legible so the student and others can understand them. Illustrations are included as appropriate to enhance clarity.

When working on a team project, as students often do in design and inquiry situations, each team member maintains his or her own journal. When data is entered, it should be labeled so as to trigger memory of what it represents, what the environmental conditions were, and what units of measurement were used. It is sometimes tempting to simply list the temperature readings, for instance, but later there may be confusion as to whether they are degrees Celsius or Fahrenheit.

DESIGN FOLIO

The Design Folio may be used to document team investigations and design progress in addition to or in place of the Design Journal. The folio provides much more scaffolding for the student, and might be very appropriate for use by high school students in the lower grades or by students new to the design process. The main points spelled out in the Design Folio should also be addressed in the journal, but the folio presents this intent more explicitly and formally. The Design Folio is a structured guide to assist students in planning and developing design solutions. (See *Pedagogical Framework*, Appendix 2, see www.nyscate.net, for the NYSCATE Design Folio pages.)

9. Teaching for Conceptual Change—and Constructivist Learning Theory

Overview. While excellent teaching has occurred throughout human history, recent cognitive research can truly be said to have created the basis for a science of teaching. In particular, constructivist learning theory explains why learning is not necessarily an outcome of teaching and suggests instructional strategies that are consistent with what we know about how students learn.

Cognition principles. Several principles about cognition have been found to be true:

- Codified information cannot be "transmitted" as personally meaningful knowledge by the actions of a teacher "on" a learner. Equating teaching with signal transmission and learning with passive reception undermines "meaningful" learning. Meaningful learning occurs when new information is related to students' prior knowledge in a nonverbatim fashion that encourages flexible, creative expression in novel situations.
- Learning is a psychologically active, constructive process in which an individual selectively perceives, filters, organizes, transforms, and responds to sensory experiences by modifying internal cognitive structures. Learning is making "new connections"; it is an iterative process of building conceptual bridges as successive approximations between the known and the unknown.

Personal meaning making. Students of any age are not blank slates or sponges; they bring a considerable amount of prior knowledge (and neurological sophistication and capabilities) from other less formal learning settings. This personal "meaning making"starts at birth and continues for a lifetime. The drive to "make sense" and achieve mastery is innate; it doesn't necessarily need to be motivated by external rewards and/or punishments such as grades. People learn best when they have questions that they want answered. Effective teachers tap into this natural drive to know and be able to do by addressing the often unspoken student question, "So what, who cares (SW2C)?"

This process:

- is likely to be intuitive and qualitative; students may not even be consciously aware of their mental processing and/or faulty conceptions. Academic performance can be improved by training students in metacognitive awareness and monitoring.
- is highly personal; no two people ever experience and mentally process a given event in the exact same way. One of the benefits of cooperative learning is that articulation and discussion of diverse viewpoints provide multiple perspectives to enrich conceptual understanding and analogical reasoning skills.
- is subtle and often overlooked by teachers or, if noticed, may seem incoherent or self-contradictory. For the individual student, knowledge is organized as "internal concept maps" or schemata (psychological webs of interconnected pieces of information).
- strongly influences what can be learned from any new experience. As punster Asleigh Brilliant quipped, "Seeing is believing. I wouldn't have seen it if I hadn't believed it" and "Wherever I take my eyes, they always see things from my point of view."
- may be separable in students' minds from "schoolwork." From grade school on, teachers often attempt to "paint over" students' prior knowledge without any deliber-

ate effort to identify, integrate, or reconcile discrepancies. Typically, it is the over-coating of scholastic knowledge that "flakes off" first.

- is stable, resistant to change, and may reflect earlier, rejected historical theories, models, and explanations.

Alternative conceptions. Researchers use a variety of terms to describe the pre-instructional, personal "theories" students hold on to: *prior*, *alternative*, *intuitive*, and *primitive*. They may also describe these theories as *naive conceptions*.

- Effective instruction catalyzes student construction and cognitive restructuring by creating multisensory, engaging, minds-on experiences that result in *disequilibrium* or *cognitive dissonance* (that is, a mismatch between predictions based on their personal theories and perceived reality).
- Mastery of "basic" facts and skills need not (and should not) precede meaningful, conceptual learning and critical/creative thinking skills; the latter should be given primary attention throughout the instructional process.

Responses to contradictory information. Once identified, conceptual errors provide important information to curriculum designers and teachers interested in facilitating learning. Unfortunately, there is no straightforward relationship between the understandings of practicing mathematicians, scientists, and engineers and learning on the part of students. Students can respond in one of several ways when their existing conceptions about natural phenomena are challenged by new, potentially contradictory information:

- As a result of confusion and frustration, they can reject both their own and the standard practitioners' conception and stop trying to understand. Students who repeatedly find themselves in this situation in a course typically drop out mentally and don't pursue subsequent courses at higher levels.
- They may fail to see the discrepancy and interpret the phenomenon on the basis of their prior conceptions and subsequently perform poorly without knowing why.
- They may see the discrepancy but ignore it (i.e., reject the standard view and cling to their prior conceptions). If this occurs only in restricted contexts, the student may actually test well in the course but is likely to resort to a memorization and regurgitation approach.
- They may see the discrepancy and find the standard viewpoint to be more intelligible, plausible, and fruitful than their own. In this case, they may:

1. partially accept the standard view and try to amalgamate it with a somewhat modified version of their own with variable degrees of success depending on the cognitive demands of testing;
2. reject a highly restricted set of their own beliefs and supplant them with what the instructor wants without full understanding and integration with prior experiences; or
3. significantly modify or replace a host of related cognitive structures and reinterpret and integrate past experiences in light of the "new, improved" theory. (This is the most desirable outcome.)

It is impossible to predict which avenue a student will take when conceptually challenged. More importantly, students will sometimes parrot their newly "acquired" conception while still clinging to their alternative conception, or they will believe that the standard conception only covers that particular event and does not generalize to other similar phenomena. Such a belief accounts for a particular student's high achievement on a formal test yet a failure to apply this documented "understanding" to a subsequent laboratory, field, or everyday experience. This concept, while "understood" by the student, has never been personally embraced and assimilated into his or her conceptual framework of how the world works.

Research on making information meaningful. Cognitive research argues that for students to transform teacher and textbook information into personally meaningful and usable knowledge, they must be:

- motivated to engage in the difficult but rewarding task of minds-on restructuring of their prior knowledge. Since misconceptions may offer adequate explanations of everyday phenomena and seem logically self-consistent, the identification, confrontation and, if necessary, refutation of students' prior ideas are critical to effective teaching.
- given multiple contexts and sufficient time to interact with fundamental concepts and their colleagues in ways that engage multiple senses and "intelligences." (School tends to emphasize logical-mathematical and linguistic intelligences while neglecting spatial, bodily-kinesthetic, musical, and inter- and intrapersonal intelligences.)
- encouraged to express their evolving understandings through a variety of channels (e.g., oral and visual reports, musical creations, dramatics and role play, simulations, creative movement, models) and have their ideas debated and tested by you and their peers, further experimentation, and authentic assessment.

10. Using Problem-Solving Models

Overview. A problem has been defined as a situation in which a gap exists between where a person is and where a person wants to be, but that person doesn't know how to get there. In light of this definition, it is interesting to note that the Chinese symbol for *problem* or *crisis* is the same symbol used for *opportunity*. Though this positive meaning of the term *problem* is not a common perception, human beings confront problems every day of their lives. Adolescents have had many experiences with problem solving by the time they reach the high school classroom. Unfortunately, the similarities and differences in the following areas of problem solving are seldom noted:

- the informal techniques people use in daily living (e.g., trial and error, following the practices or advice of peers or the media),
- the quantitative algorithms used in academic, mathematical "exercises" (which typically lead students to focus more on completing the task of obtaining the single "right" answer than on developing more general skills and understandings),
- the more formal strategies used in investigations (when the most interesting and productive results are often "failed" experiments that do not confirm our prior expectations), and
- the combination of techniques used in resolving MST issues and debates in a democratic society.

As a result of these similarities and differences, adolescents either fail to make use of effective strategies or they apply strategies inappropriately. Classrooms that engage in MST activities such as those found in the NYSCATE modules provide a unique arena to clarify, synthesize, and enhance problem-solving skills in all four areas. For inquiry the problem is to explain the natural world, whereas for design the problem is to produce a product or an effect.

Essential skills and dispositions. The need for schools to develop integrated problem-solving skills is a central focus of New York State's *Learning-Centered Curricu-*

lum and Assessment (April 1994). This document lists Essential Skills and Dispositions that augment the communication and disciplinary understandings reflected in the subject-specific *Learning Standards for MST* document:

- managing resources: the ability to use fiscal, material, and human resources, as well as time, to accomplish goals; the ability to monitor and assess one's own performance
- managing information: the ability to access, interpret, and use developing personal competence; the ability to take responsibility and initiative
- developing interpersonal and citizenship competencies: the ability to work cooperatively in large and small groups
- working with systems and technology and developing entrepreneurial skills: the ability to make informed judgments leading to productive activity, to experiment creatively, and to use self-evaluation to adjust and adapt
- thinking, problem solving, creating: the abilities to make connections and evaluate situations from many vantage points in order to synthesize, generate, and apply reasoned action to new, diverse, and practical life situations; to frame problems productively and seek solutions by defining, gathering evidence, drawing inferences, hypothesizing, posing alternatives, making decisions, and evaluating consequences; and to imagine, invent, and appreciate new possibilities, performances, and products.

Interplay of the creative and the critical. Examining this list of competencies, one can see that problem solving involves the active interplay of two higher level thinking skills—the creative and the critical:

- Creative thinking skills involve the synthesis and novel recombination of preexisting, potentially antithetical elements to generate a range of new possibilities. Examples of creative synthesis include Gutenberg's combination of the wine press and coin punch to produce the printing press with movable type; the engineering solution of laying sidewalks after people found and created the most efficient paths through the grass; the sport of wallyball, which combines elements of volleyball and racquetball; Mendel's application of mathematical techniques to biology; Kekule's use of a dream image of a snake grabbing its tail to develop the idea of the benzene ring in organic chemistry; Rutherford's use of the solar system analogy for atomic structure; Harvey's metaphor of the heart as a pump; and the recycling industry's view that "one person's trash is another person's treasure." The fields of science, technology, and entertainment are full of similar examples.
- Once generated, creative ideas need to be evaluated and refined, or replaced if found to be unfeasible. This is where critical thinking skills become important. Higher level skills of application, analysis, and evaluation need to be employed to separate crazy and fantastic ideas from the ideas that are simply crazy. Scientists and engineers regularly put their ideas and products "to the test." The complementarity of the creative and critical is captured by this statement: "Critical thinking saves creative from pursuing novelty for its own sake; creative thinking prevents critical from being merely reactive and negative" (Ruggiero, 1988, p. 18).

Questions/Planning. In light of constructivist learning theory and the premises of MST education, engaging students through motivational, relevant questions, problems, and/or issues is paramount to success in teaching. This engagement does not mean, however, giving students a completely and narrowly defined exercise. Students must find and define the problems they wish to explore, and devise a plan for attacking the problem. Research in problem solving suggests that the best approach is to have students first collect some general information about the phenomenon in question, gather some preliminary evidence that seems relevant, and then engage in a process of proposing, arguing, and refining through group discussion or peer-to-peer interaction.

The importance of empowering students to frame their own researchable questions cannot be overstated. Consider sharing with your students quotations such as John Dewey's "A problem well stated is half solved" and James Thurber's "I'd rather know some of the questions than all of the answers."

Discrepancies as motivators. Events that create cognitive discrepancies and inconsistencies are especially powerful motivators. The six general categories of discrepancies identified include:

- a goal to achieve without a means to achieve it;
- a difference between what the student expects to observe and what the student actually does observe;
- a lack of knowledge—others may know the information but the student does not;
- a difference between what the student has been told is true and what the student has personally verified;
- a conflict (internal or external) between interpretations, opinions, attitudes, and values;
- a difference between an existing set of conditions (what is) and a desired state (what should be).

Brainstorming. One tool for problem finding is brainstorming. The rules for effective brainstorming are simple to state, but students will need practice to master them. The rules may be remembered by the acronym DOVE.

D	Defer judgment: Think/create/diverge first, judge/critique/converge later after the brainstorming phase is complete.
O	Offbeat ideas: "Impractical" ideas often trigger other, quite useful ideas; as Alfred North Whitehead said, "Almost all really new ideas have a certain aspect of foolishness when they are first proposed."
V	Vast quantity: Nobel chemist Linus Pauling stated, "The best way to get a good idea is to get a lot of ideas," and French philosopher Emile Chartier said, "Nothing is more dangerous than an idea when it is the only one you have."
E	Elaborate, combine, expand, improve, and piggyback on ideas of others.

To introduce your students to this technique, use the chalkboard or large sheets of paper to record all ideas.

Skills/Obtaining data. The conventional journalist questions of who, what, where, when, why, and how need to be explored. In addition to hands-on laboratory investigations, the NYSCATE modules call on students to use data-collection techniques such as interviews, surveys, field observations, presentations by outside authorities, simulations, mass media analyses, map reading, and design-build-test-redesign projects.

Organizing data. Data-collecting activities naturally lend themselves to student-generated tables, charts, and graphs. Beyond these, the use of Venn diagrams and other graphic organizers, posters, murals, and computer databases and spreadsheets is encouraged.

Analyzing data. Elementary statistics (e.g., mean, median, mode) and simple trend analysis can help students to see the power of mathematics to address real-world problems and issues and the importance of objectivity and quality research design.

Specific skills include the ability to: distinguish fact from inferences, opinions, or propaganda; evaluate the integrity of different sources of data (e.g., *National Enquirer* vs. *Scientific American)*: evaluate the relevance of data to a particular problem or issue; compare information for supporting and contradictory arguments from one source or across multiple sources; play devil's advocate with one's own ideas; and suspend or discard personal theories in light of cogent contradictory evidence.

Product Generalizing and/or synthesizing from data. More so than with conventional laboratory exercises, MST activities motivate students to explore the "so what does this all mean" and "how can I use this information" questions. Here again, the technique of brainstorming is useful in generating a range of solutions.

NYSCATE modules typically focus student attention on concrete actions that individually and/or collectively they can take "to be part of the solution, rather than part of the problem."

In both research and MST issue resolution, the process of problem solving is iterative; that is, each answer or solution generates new questions or problems, and subsequent data often forces problem solvers to reconsider and revise their past answers/solutions.

General recommendations. Beyond engaging students with interesting questions and activities and teaching some techniques such as brainstorming, there are some general recommendations that you can follow to help develop students' problem-solving skills:

■ Emphasize process as well as content in your instruction, and include the assessment of problem-solving skills as part of the evaluation plan.

■ Engage multiple intelligences with a variety of instructional methods including concrete representations, visuals, hands-on activities, and cooperative learning experiences that promote inquiry, design, and social construction of knowledge.

■ Provide intellectually challenging experiences that create conflict with previously held ideas and that arouse curiosity without creating too much frustration; teach in a way that exposes possible misconceptions and challenges students to push the limits of their knowledge and skills.

■ Create safe, supportive environments in which students' "miss-takes" are seen as both natural and informative for you and your students.

■ Model how to approach problems and create/modify mental models; make your own implicit, automatic procedural knowledge explicit; and encourage students to visually represent problems.

■ Provide frequent practice in problem-solving activities so that skills and self-confidence develop; allow students to practice the same skill in different contexts to promote transfer.

■ Provide explicit feedback, and help students develop their own metacognitive and self-evaluation skills through discussions with you and fellow students; focus discussion on problem representation and appropriate solutions rather than simply finding the correct answer.

■ Promote deep-level rather than surface-level learning by encouraging dialogues with others and discouraging mindless use of formulas and algorithms that may produce "correct" answers without corresponding understandings.

■ Supply students with words, concepts, and theories about critical thinking skills to help them face future tasks.

■ Motivate students to believe they can succeed by providing opportunities for easy-to-achieve success.

Research identified limiting attitudes and behaviors. Research on both academic and industrial problem solving has also identified a number of attitudes and behaviors that block or limit creative and critical thinking and problem solving:

- not adequately defining the problem; having the tendency to over- or understate the problem, i.e., not seeing the tree for the forest or the forest for the tree;
- stereotyping and seeing only what you expect to see; not noticing, pursuing, or properly weighing contradictory evidence;
- having "hardening of the categories"; not being able to use analogies and metaphors to make the strange familiar and the familiar strange;
- overlooking, ignoring, or not noticing the familiar; being trapped by past successes and what we know;
- believing that "fear[ing] to make a mistake, to fail or take a risk" is perhaps the most general and common emotional block to problem solving instead of having a "let's try it and see" attitude;
- believing that qualitative data, intuition, and feelings are not useful and that solutions should be based solely on quantitative data, reasoned logic, and facts. The history of science and technology is full of stories of intuitive leaps and serendipitous discoveries (e.g., penicillin, vulcanization of rubber, saccharin, X-rays, electromagnetism, Teflon, radar, etc.). Einstein said, "I believe in intuition and inspiration; at times I feel certain I am right while not knowing the reason";
- engaging the critical skills before trying out the creative, and devoting more time and energy to proving an idea wrong than playing with it and modifying it to make it workable;
- having constipated thinking; being stuck in the rut of one's own ideas without adequate input from others;
- not distinguishing reasoning from rationalizing;
- having a lack of attention to internal, metacognitive processes and therefore an inability to get oneself "unstuck";
- having the belief in a single, one-size-fits-all, "right" answer; not having the ability to adequately consider alternatives;
- having a negative connotation for the term *problem*.

MST overlappings. Mathematics, science, and technology have been closely linked throughout history; developments in one have spurred advances in the other. Although each of the fields has its own character, integrity, and methodology, there are numerous ways in which the fields and their processes overlap.

Individually and together, mathematics, science, and technology provide insights into philosophical and practical areas of human concern. Galileo contributed to the rise of modern science when he pioneered the use of mathematical models. His discovery of the moons of Jupiter was possible only because of the invention of the telescope. The telescope, in turn, has helped scientists learn much about the solar system and beyond.

Whole areas of mathematics have developed from one or another of the empirical sciences. Conversely, some areas of science developed from the knowledge of pure mathematics and the need to understand the theoretical underpinnings of technological systems. Technology uses mathematics and science knowledge to turn resources into products, systems, and services. Most problems in the real world require interdisciplinary solutions; thus, educating students requires that they understand the relationships among mathematics, science, and technology.

Mathematics, science, and technology are each distinguished by specific characteristics and essential mental processes that define the way mathematicians, scientists, and technologists approach their work. Mathematicians employ *reasoning* and *analysis* to explore relationships among abstractions; scientists use methods of *inquiry* when observing the natural world and building explanatory structures; technologists (such as engineers, architects, and industrial designers) *design* products and systems to create the human-made world.

Mathematical analysis, scientific inquiry, and technological design each reflect unique combinations of procedures, knowledge, and skills; however, there are elements embedded within them (such as investigation, generating explanations, and modeling) that are transferable to other areas of study, thus making these processes particularly powerful. Mathematical analysis is often employed in the contexts of technological design and scientific inquiry. Analysis is undertaken when data is quantified and results are assessed.

Although inquiry is the core process of science, it also is used in technology to investigate how things work, to examine the effect of changing one or more variables, and to troubleshoot defective systems and components. It is used in mathematics to find alternative solutions.

Although design is the core process in technology, it also is used in science to design experiments and apparatus and to create special tools or procedures. It is used in mathematics to design models and manipulatives. Mathematics is used as a design tool to develop computer simulations and to predict and explain the behavior of systems and structures.

11. Increasing Participation of Females and Underrepresented Minorities in the MST Classroom

Although individual women and members of Black and Hispanic minorities have attained the highest levels of scientific and technological education and achievement, as a group they remain significantly underrepresented in sci-tech careers. Nationwide, data indicate that White women make up 43% of the U.S. population but only 10% of our practicing scientists and engineers; Blacks 12% of the population but 2% of scientists and engineers. As educators, there are several reasons why we should be concerned with this data. First, it reflects a lack of equal access, for whatever reasons, to financially and intellectually rewarding sci-tech careers. Second, a shortfall of scientists and engineers is anticipated from the White, male-only category. Nationwide, ethnic minorities presently comprise about 34% of the school-age population and White females another 33%. Drawing all future scientists and engineers primarily from the remaining 33% of the school-age population (i.e., White males) is neither desirable nor feasible. Third, the relative absence of strong female and minority perspectives and contributions results in a lack of balance in science and technology. Simply put, the fields of science and engineering need women and minorities every bit as much as women and minorities need MST.

Significant gender and ethnic differences in attitudes toward and performance in science and mathematics classes, as well as the extent of in-school and out-of-school hands-on sci-tech experiences, have been consistently documented in late elementary/early middle school students (ages 11 - 14). These differences undoubtedly lead to differences in participation in senior high electives in the physical sciences and mathematics, and these differences in participation in turn lead to the disproportionately low numbers of women and minorities who pursue postsecondary studies in the physical sciences, engineering, and mathematics. Many factors may underlie these patterns of sci-tech math "phobia" and avoidance.

Psychological: Adolescent females and minorities may harbor faulty perceptions of MST, the world, and/or themselves that are based at least in part on the cultural factors listed next.

Cultural: Implicit, unchallenged gender roles, differential treatment, and expectations discourage broader participation.

Sociological/Structural: M, S, and T as they are currently practiced are White male domains that are opposed to the sensibilities and values of the "underrepresented."

Biological: There are differences in brain symmetry and neurophysiology in men and women. Scientists score higher on spatial ability tests than nonscientists, and boys score higher than girls on these tests (as opposed to verbal ability tests). Therefore, it can be said that the underrepresentation of women reflects a "natural" inequality.

Though recent and ongoing brain research has suggested that gender influences brain development from early on in fetal development, no reputable scientists are arguing that a narrow edge in one area of intelligence predisposes males to be better scientists than females (especially since males fall somewhat behind females in other areas). On the other hand, research focusing on the brain and on multiple intelligences does suggest that by using a narrow range of traditional instructional strategies, we are giving White males a relative advantage but shortchanging them in terms of developing the full range of intelligences.

As a classroom teacher, you can do little about sociological and structural "bias" in the fields of science and engineering. However, knowing about it enables you to consider the extent to which you may be unknowingly contributing to, or at least not directly challenging, gender and ethnic biases that discourage females and minorities from participating fully in class. Numerous "draw-a-scientist" studies dating from Margaret Mead's work in the late 1950s to the present have found that many students perceive science as a domain of slightly unkempt, socially backward, somewhat "mad" but benevolent, middle-aged White males, who wear lab coats and glasses in their solitary, indoor work. Undoubtedly, the popular culture of films and books contributes to this stereotyped image. The stereotypes for mathematicians and engineers are no kinder. Do our MST classrooms also indirectly convey the message of exclusion?

Try thinking back to your school experiences. What was school like for you? Did you like it? Hate it? Tolerate it? Become excited by it? When adults write about their early experiences, they reveal how students classify themselves as science/mathematics/engineering "types" or "outcasts" or "failures." Students recall experiences that led them to feel like technical "outsiders" or "insiders."

The insider/outsider dichotomy as it relates to mathematical learning was first documented in research by Sheila Tobias. An insider is someone who takes for granted that he or she will do well in a technical subject and is willing to tackle such courses on his or her own terms. Whatever the school experience, insiders believe they can handle it. Typically, but not exclusively, insiders are White males who have received messages from popular culture that White males "do" MST. Who are the outsiders? These students frequently feel anxious about their ability to do MST and see such academic areas as alien to themselves. Outsiders have no sense of entitlement toward

MST and are not accustomed to seeing people like themselves portrayed as scientists, mathematicians, or engineers.

Surprisingly, research has shown that male and female teachers alike have lowered expectations for females, often unknowingly, and interact with their male students very differently than with their female students (e.g., in regard to questions, discipline, encouragement, help, etc.). Similarly, the devastating effect of lowered expectations and self-fulfilling prophecies has been well documented with respect to minority students. Self-administered checklists/quizzes, peer observations, and analysis of videotapes of your own teaching are all recommended strategies for eliminating potential biases.

Ask yourself if you are one of the science and technology teachers who often do the lab or project for your female students who ask for assistance, while encouraging the males to figure it out on their own. If you are, you are not helping these females; instead, you are communicating the message that they are not capable and that science (or math or engineering) is a male province in which assumed female squeamishness and lack of mechanical aptitude have no place. These assumptions are examples of the cultural stereotyping that prevents females from fulfilling their potential in science and technology.

Certain teaching practices have been shown to promote an "MST for all" environment. Teaching students about MST issues will allow you to invite all those students who feel like outsiders into the enterprise. Research validates that making connections between science and technology is a prerequisite to inviting females of all ethnicities and minority males to MST, and is extremely beneficial for all outsiders. Research also suggests a range of other teaching practices that create an "MST for all" environment. Specifically, you are encouraged to:

- Set MST in a real-world context by integrating information on the personal and social applications of concepts. Stress relevance and consider ethical issues related to the concepts (explore potential benefits and costs/risks/burdens). Link physical principles to biological applications, especially those involving human health.
- Employ a variety of hands-on, minds-on teaching techniques instead of lecture-only techniques, and include cooperative learning strategies as opposed to using competitive ones exclusively. The success of cooperative learning techniques has been demonstrated in engaging potential outsiders in science and technology projects. When cooperative learning groups are carefully planned to include a heterogeneous group with respect to gender, ethnicity, and ability, all students more readily contribute their talents to the particular MST problem being studied.

At whatever level you teach, you can develop strategies of encouragement and inclusion. In the classroom, you will need to listen to the small, soft voices of outsiders in the face of frequently more vocal, assertive insiders, especially in the upper grades. Students who do not feel entitled to doing and knowing science and technology frequently pull inward and do not express themselves in class. All students must be actively engaged in classroom conversations, and all students need to hear about scientists of both genders.

- Encourage active participation by all, not just a few vocal students.
- Discourage passive nonparticipation and resource "hogging."
- Monitor laboratory activities to ensure that all students have ample opportunity to do MST.

- Provide ample time for comments, and encourage extended answers; avoid rapid-fire, recognition-recall questions.
- Use equitable (nonsexist and nonracist) expectations, language, examples, and curricular materials.
- When appropriate, feature the accomplishments of historical and present-day women and minority mathematicians, scientists, and engineers, including those from other cultures, to break down stereotypes.
- Use varied, aesthetically appealing illustrations and activities that encourage the use of multiple intelligences beyond the logical-mathematics and linguistic.
- Stress safety precautions when introducing new laboratory techniques.
- Include field trips, audiovisual presentations, and speakers (particularly members of underrepresented minority groups) to encourage all students to consider science and engineering as possible careers. People who have traditionally been excluded from sci-tech careers have not been socialized to believe they can succeed in these fields. Students need to meet people who can serve as mentors and role models.
- Stress both basic skills and critical and creative learning by following the precepts "less is more" and "uncover rather than cover."
- Communicate with guidance counselors or advisors to ensure that students are not prematurely advised against taking "tough" science and mathematics courses.
- Expand the caricatured image of MST:

From	To
PURE	applied/interdisciplinary
LOGICAL	alogical/creative/imaginative
MATHEMATICAL	artistic/aesthetic
NEUTRAL	value-bound, political
OBJECTIVE	subjective
INTROVERTED/ASOCIAL	social
COMPETITIVE	cooperative

12. Sharing Results—Reports and Presentations

Both the laboratory/Design Report and the class presentation describe the problem that was solved, how the solution was accomplished, what conclusions were reached, and what new issues were raised. The report, a formal device completed by individual students, and the class presentation, an informal device planned and delivered by design teams, in effect mirror the format of the NYSCATE informed design loop (see loop). The informed design loop features the following phases:

Phase 1: Clarify Design Specifications and Constraints.
Phase 2: Research and Explore the Problem.
Phase 3: Generate Alternative Designs.
Phase 4: Choose and Justify Optimal Design.
Phase 5: Construct a Working Model.
Phase 6: Test and Evaluate the Design Solution.
Phase 7: Redesign the Solution with Modifications.

THE DESIGN REPORT

The Design Report is a short paper (about three pages) written by individual students, summarizing the total experience for the module and highlighting findings. It should follow this format:

Design Introduction. Explain the problem, noting specifications and constraints, to establish the "why" of the design.

Research/Investigation Outcomes. What currently existing solutions did you find to solve this problem? What problems and issues did you uncover that relate to this Design Challenge?

Alternative Designs Generated. Describe the alternative solutions you generated. What is your justification for the alternative you selected? How did that alternative guide your preliminary design?

Choice of and Justification for Optimal Design. Describe engineering, mathematical, and scientific data, including that collected during your research and investigation, to assure yourself that the proposed design solution meets specified criteria.

Working Model Construction. As you constructed the model of the chosen solution, what modifications did you make? How did those changes refine the design?

Test and Evaluation of the Design Solution. Describe your test of the design solution. What data did you collect? Describe the extent of agreement between your analysis of the data and the specifications and constraints. How successful was your design solution?

Wrap-up and Redesign Recommendations. In this concluding section of the report, indicate how your application of science and math concepts enhanced the performance of your design. Indicate how these understandings might be applied to improve your design solution.

CLASS PRESENTATION

You might want to have each student team that worked on the Design Challenge and KSBs for a module make a class presentation. Students are expected to use multiple forms of media (e.g., presentation software, color overheads, video, computer animation) to enhance their presentations. The presentation summarizes the work involved in researching, collecting and analyzing data, developing models, improving the design, and making suggestions for further refinements. At the end of the presentation classmates have an obligation to ask probing questions and challenge team findings.

Here is a list of presentation considerations for your students:

- Oral communication is an important part of education and a valuable asset in technical careers. Few of us can stand up and talk about a subject without preparing what we want to say. As in writing, a person must have a clear idea of what it is he or she wants to express. A good speaker typically jots down topics to be covered and the integrating theme that connects them, and builds a presentation with both in mind. The talk should not be too elementary or sophisticated; in either case, contact with the audience might be lost. True communication is a two-way street—transmission and reception must both occur.
- How should the talk be delivered? Use notes, but do not read. Plan to expand on key topics. Once you've gathered all the material you need to make the presentation, make an outline, prepare note cards, and make a trial talk to yourself. The trial should be timed; make sure you speak clearly and not too fast. Once you're satisfied that

you've included all the information you intend to convey, try out the presentation on a friend. Then go over what is to be said multiple times.

- Visual aids are terrific. They provide something for the audience to see or read while listening to your talk and help to maintain awareness of the point under discussion. You might include transparencies, flip charts, or PowerPoint presentations. An advantage to using visual aids is that they become an outline and a source of notes. Since the topics listed on the chart or graph can be expanded upon, you might not have to use notes at all. Keep the diagrams and charts simple, because the audience will have to read them and listen at the same time. Complicated diagrams are likely to turn an audience off.
- Just as the appearance of a written report affects how people judge its content, so the speaker's appearance affects audience reaction to what is being said. You should look presentable, neat and well dressed. Make eye contact with the audience, and speak clearly and loudly enough so the audience can hear. People do not want to strain to understand what is being said. You know what is to be said and what the connections are, but the audience does not; speaking slowly helps them follow along.
- Consider engaging the audience in some way during your presentation. Ask them a question or their opinion, ask them to predict a solution's effectiveness, present a very short task for them, have them help with a demonstration of the solution model, ask them for redesign suggestions, or in some other way involve your listeners.

13. Assessing Student Work/Actions

Running parallel to state and national calls for curriculum revision that gives more attention to conceptual learning, higher level thinking skills, and real-world applications are calls for a revision in assessment practices. In the introduction to *In Pursuit of Excellence and Equity: Transforming Testing in New York State*, Dr. Annette Saturnelli states: "At the end of the nineteenth century, tests were developed and used to classify, rank and filter out individuals. Now, at the end of the twentieth century, new forms of assessment are being developed in order to create teaching and learning opportunities, and to identify, nurture and fully develop the talents of all children . . . to open, not close doors for students."

New York State's Learning-Centered Curriculum and Assessment, published in April 1994, is even more explicit:

> . . . curriculum, instruction and assessment must be designed to encourage active learning, emphasizing in-depth understanding along with applications of knowledge in new and complex situations, rather than rote responses . . . must contribute to students' abilities to use their minds well; to think critically and creatively; to make informed and reasoned judgments; to produce and invent as well as to critique and analyze; and to develop habits of personal responsibility and concern for others . . . must also be interrelated and interconnected . . . within and across disciplines and between school and non-school performance settings . . . must be embedded in the teaching and learning process, rather than 'delivered' out of context at discrete testing moments . . .. It should provide information about student potentials as well as progress, and be motivating to students, teachers, and schools.

Clearly, what is being called for is an expansion of the idea that paper-and-pencil assessments, and multiple choice testing, equal grading. Buzz phrases such as "alternative, learner-centered, curriculum-embedded, performance-based, authentic assessment in the service of instruction" suggest a shift from testing as a carrot-and-stick means of motivating/coercing students to study something that they find uninteresting, to a situation in which "authentic" curriculum, instruction, and assessment form a seamless tapestry. In "authentic" assessment "teaching to the test" (and even through the test) becomes a commendable activity in which individual, collective, diagnostic, and formative evaluations are used to access and assess students' "miss-takes" and misconceptions and to inform instruction. Clearly, this kind of assessment is broader in scope than traditional assessments, which focus on a single reference point (such as a unit or chapter) to generate a grade.

Action projects: In between these extremes there are numerous techniques that you can use to add context and meaning to your lessons and assessments. Even conventional multiple choice items can be made more authentic by: (a) focusing them on application-level or higher level thinking skills—this is often easily done if several items are linked to a brief, textual paragraph or data set; (b) modifying the normal response to include a written justification statement—this allows a glimpse into student reasoning; you may find that some students get the answer wrong for the right reasons and vice versa; and (c) designing assessment distracters that target specific, common student misconceptions. Additionally, open-ended questions that require students to write a short essay-type answer, complete or design a concept map, manipulate data on a chart or graph, or prepare a sketch related to real-world applications have been used on traditional exams by many teachers.

The NYSCATE modules go beyond developing students' conceptual understanding to involving them directly in authentic, real-world problem solving, decision making, and responsible action taking. For this reason, assessments built solely or even primarily around traditional, low-level multiple choice, true-false, and short answer items are insufficient to measure student achievement. An overall classroom, building-level, or district MST assessment plan should integrate a wide array of techniques and evaluation instruments, including some techniques employed by experienced teachers in other discipline areas as cited above.

Well-written multiple choice tests that include application, analysis, synthesis, and evaluation questions are only one of a variety of useful assessment strategies. Unfortunately, the overuse of multiple choice testing (especially low-level knowledge and comprehension items), to the exclusion of other techniques, predisposes students to: (a) expect a range of reasonable options to be presented to them when confronted with problems; and (b) believe that all problems have a unique, singular, "right" answer. Real-world problems and issues are quite different in this respect from schoolbook, drill-type exercises.

While most teachers acknowledge the close relationship that exists between mathematics and science, you may not be aware of the relationship between science and technology education. You would probably be surprised to discover the extent of congruence and even overlap among the New York State MST core curricula. All of these publications recommend concrete, multisensory, hands-on/minds-on constructivist teaching; a systems perspective; creative use of educational technology; and development of collaborative and decision-making skills in the context of exploring issues. The *Learning Standards for Mathematics, Science and Technology* document makes the idea of integrating the skills of mathematical analysis, scientific inquiry, and technological design even more explicit in two of the standards and one of the five principles:

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

Standard on Interdisciplinary Problem Solving: Students will apply the knowledge and thinking skills of mathematics, science, and technology to address real-life problems and make informed decisions.

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

The *Learning Standards for MST* document goes on to state:

> Real life takes place in a holistic context with all of us learning continuously through multidisciplinary experiences. The historic separation of information into discrete streams of content blurs the natural relationships among things taught and learned for teachers and for the students. Schooling, to be most relevant, should instead mirror reality with students engaged in interdisciplinary activities anchored in real-world problems and environments. Because of the special relationship that exists among mathematics, science and technology, an integrated, interdisciplinary approach is especially appropriate . . . this document is about . . . the process of 'reintegrating' mathematics, science, and technology, or rediscovering, uncovering, or restoring the natural linkage among these three disciplines.

The assessment of student design work considers many factors and focuses on the design process as well as the finished product (design solution). Each component of design-related student activity is represented in rubrics that are generic to all NYSCATE design activities. However, you can tailor the generic rubrics to a particular assignment, and you should discuss them in advance to make students aware of the evaluation process. You can assess student design processes and products by reviewing students' Design Journals or Design Folios; Design Reports; and team presentations to the class. Multiple choice, short answer, or extended response questions that assess design understandings, content knowledge, and technical skills are also appropriate.

Assessment of students' Design Reports or Design Folios involves consideration of multiple factors; you must focus on the process as well as the product.

The scoring scale that follows is consistent with a scale developed by the National Council of Teachers of English:

4 = exceeding the level that you target in teaching
3 = meeting the level you target in teaching
2 = developing to the level you target in teaching
1 = emerging

The following set of preliminary design assessment rubrics is general. You can tailor them to particular assignments. As the NYSCATE project conducts field-testing, pools of student work will be collected for various modules, and benchmark papers will be identified to exemplify the differences among scoring categories. If you use these preliminary rubrics, you should present them to and discuss them with your students ahead of time so they become aware of and a part of the process through which they are being evaluated.

THE DESIGN PROCESS

A. Explained problem and identified constraints and specifications.

4. Explained the problem in detail and from this context illustrated the necessary constraints and specifications.

3. Explained the problem in a few sentences, and provided two constraints and two specifications.
2. Briefly explained the problem, and provided one constraint and one specification.
1. Did not explain the problem, and provided no or only one constraint and specification.

B. Researched the problem and developed information from Knowledge and Skill Builders.

4. Knowledge and Skill Builder completely and accurately performed with further investigations developed as a result of the investigations.
3. Knowledge and Skill Builder was completely and accurately performed.
2. Knowledge and Skill Builder was incompletely performed, but attempts were made in all three areas.
1. Knowledge and Skill Builder was poorly performed. Not all areas were attempted.

C. Justified optimum design.

4. Provided three to four alternative solutions. Used sketches to represent solutions. Undertook math, science, and technological investigations that were used to justify optimum design.
3. Provided two to three alternative solutions. Used sketches to represent solutions. Undertook science and technological investigations that were used to justify optimum design.
2. Provided one to two alternative solutions. Used sketches to marginally represent solutions. Undertook minor investigations that were used to justify optimum design.
1. Provided one solution. Used sketch to marginally represent solution. Few or no math, science, and technological investigations were used to justify optimum design.

THE DESIGN SOLUTION

A. An accurate sketch of your final, as built, design was drawn.

4. Drawing was on graph paper to scale with all elements included. Isometric view or multiple views (top, side, and front) were shown.
3. Drawing was on graph paper to scale with all elements included. Drawing showed the design in two dimensions—a flat view.
2. Drawing was on graph paper reasonably to scale with most elements included.
1. Drawing was not to scale and important elements were missing.

B. Materials and tools were planned and used appropriately in constructing project.

4. Prepared a list of materials and tools present and included an explanation of how they would be used appropriately in the construction.
3. Prepared complete list of materials required and tools necessary to fabricate with these materials.
2. List of materials was essentially complete; some tools required were not mentioned.
1. Mentioned only a few materials and tools.

C. The solution worked. It met the design specifications and constraints.

4. The solution solved the problem statement; this was explained in the write-up along with how the specifications and constraints were addressed and/or how the design was modified to ensure their being met.
3. The solution solved the problem statement and the constraints and specifications were met.
2. The solution solved the problem but not all constraints and specifications were met in doing so.
1. The solution did not solve the problem; constraints and specifications were not met.

D. The design was creative.

4. The solution was unique; never or seldom has this design been formulated.
3. The solution was functional, but not unique. Similar solutions were common.
2. The solution was similar to others; it may have been a modification or interpretation of someone else's solution.
1. The solution appears to be copied from someone else's work.

MATHEMATICAL, SCIENTIFIC, AND TECHNOLOGICAL CONNECTIONS

A. Presented results in graphs and charts.

4. Graphs and charts were neatly drawn with graphic illustration. Graphing software, if appropriate, was used.
3. Graphs and charts were drawn neatly on graph paper. Labels were appropriate.
2. There were some graphs and charts drawn with moderate care.
1. Charts and graphs were poorly done. Information was missing.

B. Used accurate analysis and calculation.

4. Used appropriate mathematical and scientific analysis to inform the design. Conducted the analysis in a logical fashion, clearly showing methodology used and justifying procedure.
3. Used appropriate mathematical and scientific analysis to inform the design. Conducted the analysis in a logical fashion, clearly showing methodology.
2. Used appropriate mathematical and scientific analysis to inform the design. Some minor errors were made.
1. Significant errors were made in analysis and procedures.

C. Tested the design.

4. Conducted the test in a reliable and scientific fashion with multiple tests run to demonstrate repeatability. Discussed why the testing was reliable and described efforts made to ensure it would be.
3. Conducted the tests in a reliable and scientific fashion with multiple tests to demonstrate repeatability.
2. Conducted the test once. Did not show reliability or repeatability of data.
1. Did not perform testing of design.

D. Provided conclusions based on the testing and made recommendations for improvements for redesign.
   4. Analyzed the results from testing and made sense of them. On the basis of this analysis, we made recommendations for design improvements and then modified the design and retested to show the benefit of the modifications.
   3. Analyzed the results from testing and made sense of them. On the basis of this analysis, we made recommendations for design improvements.
   2. Analyzed the results and suggested design improvements but justification was missing.
   1. Did not reach conclusions from testing or recommend design modifications based on the testing.

WORK HABITS

A. Worked collaboratively with classmates.
   4. Worked cooperatively with others both as a leader and as a follower. Helped focus the team on the task at hand and assisted others.
   3. Worked cooperatively with others, assisting occasionally.
   2. Worked alone, completing assignments.
   1. Worked alone. Did not complete assignments.

B. Completed assigned tasks in a timely fashion.
   4. Maintained a journal/daily log of project. Completed personal assignments on time, and assisted others in keeping team on time.
   3. Maintained a journal/daily log of project; personal assignments were completed on time.
   2. Most personal assignments were completed on time; journal/daily log was erratically maintained.
   1. Assignments were turned in late or were incomplete; journal/daily log was not maintained.

COMMUNICATION AND PRESENTATION

A. Design portfolio was complete and neat in appearance.
   4. All sections of portfolio were completed; portfolio was typed, and sentences were complete and grammatically correct. There were no spelling errors.
   3. All sections of portfolio were completed; handwriting was neat and sentences were complete, grammatically correct, and free of spelling errors.
   2. All sections were attempted, and most sections of the portfolio were completed. Phrases and sentences were used; there were some grammatical/spelling errors, and handwriting was legible.
   1. Not all sections were attempted; work was incomplete. There were grammatical/spelling errors, and handwriting was illegible.

B. Actively participated in the presentation of results.
   4. Knowledgeable of own material and clearly presented same. Language skills were good. Interacted with others, and acted as team leader with support of the team.

3. Knowledgeable of own material and clearly presented same. Language skills were good. Interacted with others.
2. Knowledgeable of own material and presented same.
1. Did not actively participate. Information misunderstood.

14. Collecting Project Assessment Data

The NYSCATE modules have been evaluated to improve them as well as to gather information to attest to their effectiveness. Evaluation consists of four components:

Paper reviews of the modules are surveys completed by experts in that content area. They focus on the content, use, and relevance of the module.

Microtesting is conducted by either the module writer or someone else. It is used to examine specific aspects of the module and may include some or all of the KSBs, activities, etc. Students and teachers use *reaction surveys* to provide feedback on the module.

Piloting is carried out by a teacher other than the writer. Pilot data include teacher and student reaction forms; pre/post-assessment items related to math, science, and technology content; and sample student work. The piloting teacher is usually a colleague of the writer.

Field-testing is conducted by a group of teachers selected for that purpose. After being oriented in the use of the module, the field-testing teacher instructs a class, using the module. Field-test data that are collected include student and teacher reaction forms, pre/post-assessment data, sample student work, and final Design Reports. More detailed protocols have been developed for guiding these activities and will be provided to you if you are piloting or field-testing a module. These protocols include assessment instruments and procedures to be followed.