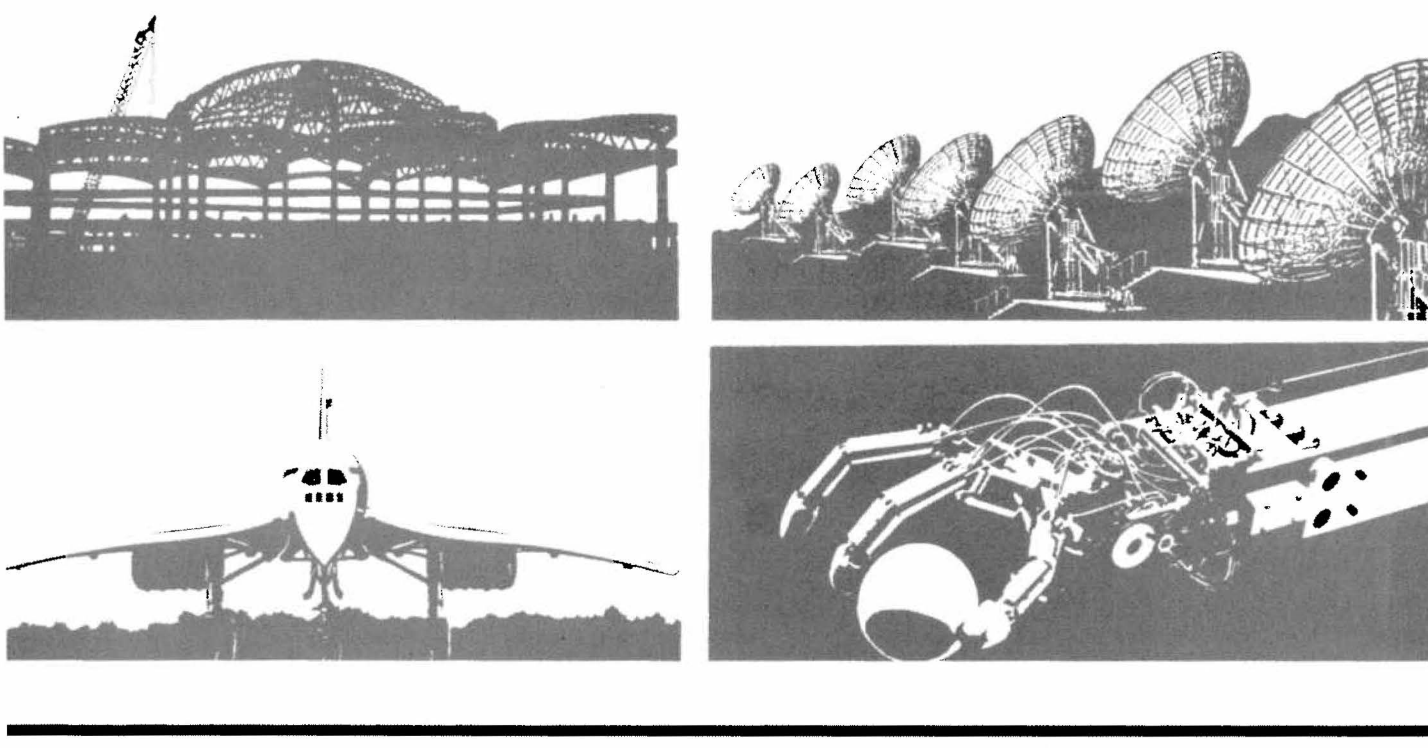
TECHNOLOGY EDUCATION
PRINCIPLES OF ENGINEERING

An MST Approach to Technology Education

Grades 9–12
Elective



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USE IN SEQUENCE: ELECTIVE COURSE

This course is one of the New York State approved electives in Technology Education. It is one of several electives courses designed to give students a firm but broad exploration of the technical world in which they live.

Students completing a high school sequence in Technology Education must take a total of one to three units of elective course work to fulfill the "elective" portion of their sequence requirement. This course may also be taken by any student as an elective. If the instructor uses this syllabus as a guide for instruction, students may be granted Regents credit for the experience. The course also satisfies the "SYSTEMS" requirement for high school Technology Education sequence.

Several courses within Technology Education offerings can be offered on one half-unit or one-unit basis. Course work earning one half-unit must comprise a minimum of 54 hours of instruction and course work earning one-unit must comprise a minimum of 108 hours of instructional time.

STUDENTS WITH DISABILITIES

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

The majority of students with disabilities have the intellectual potential to master the curricula content requirements for a high school diploma. Most students who require special education attend regular education classes in conjunction with specialized instruction and/or related services. These students must attain the same academic standards as their nondisabled peers to meet graduation requirements, and, therefore, must receive instruction in the same content areas, at all grade levels. This will ensure that they have the same informational base necessary to pass statewide testing programs and meet diploma requirements.

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

Strategies for Modifying Instructional Techniques and Materials

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

2. Identify, define, and preteach key vocabulary. Many terms in this syllabus are specific and some students with disabilities will need continuous reinforcement to learn them. It would be helpful to provide a list of these key words to the special education teacher in order to provide additional reinforcement in the special educational setting.

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

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

Infusing Awareness of Persons with Disabilities Through Curriculum
In keeping with the concept of integration, the following subgoal of the Action plan was established.

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

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

This curriculum, by design, includes information, activities, and materials regarding persons with disabilities. Teachers are encouraged to include other examples as may be appropriate to their classroom or the situation at hand.

STUDENT LEADERSHIP SKILLS
Development of leadership skills is an integral part of education in New York State. The New York State Education Department states that, "Each education agency should provide to every student the opportunity to participate in student leadership development activities." Additionally, the Department indicates that all "students should be provided the opportunity to participate in the educational activities of the student organization(s) which most directly relate(s) to their chosen educational program."

Leadership skills should be incorporated in the New York State education curricula to assist students to become better citizens with positive qualities and attitudes. Each individual should develop skills in communications, decision making/problem solving, human relations, management, and motivational techniques.

Leadership skills may be incorporated into the curricula as competencies (Performance Objectives) to be developed by every student or included within the Suggested Instructional Strategies. Teachers should familiarize themselves with the competencies. Assistance may be requested from the State advisor of the student organization related to the program area.

Students who elect to become active members of one of the student leadership organizations chartered by the New York State Education Department have the advantage of the practical forum to practice leadership skills in an action oriented format and have the potential for recognition of their achievements at the local, State, and national level.

RECOMMENDED BACKGROUND FOR TEACHERS OF PRINCIPLES OF ENGINEERING:

- College level physics and chemistry
- College math through precalculus (trigonometry)
- Computer literacy (capabilities and limitations of personal computer hardware and software)
- Technical Drawing; CAD
- Hands-on technology experience in research, design, and constructing models
- Participation in in-service program designed specifically to assist teachers to deliver this course.

RECOMMENDED BACKGROUND FOR STUDENTS TAKING PRINCIPLES OF ENGINEERING:

Sequence I Mathematics
Sequence II Mathematics
Two years of Regents Sciences

Also desirable:
Physics as pre- or corequisite
Sequence three Mathematics as pre- or corequisite
Technical Drawing/CAD

COOPERATIVE LEARNING STRATEGIES

Cooperative learning is a teaching strategy that can be used by teachers for all subject areas and at all grade levels. Because of the nature of the activities in the ***Principles of Engineering*** course and engineering skill requirements in general, the effective use of cooperative learning strategies becomes increasingly important. Students will be working in small teams to complete various assignments; it will be necessary for the teacher to have the skills necessary to structure group learning activities so that the groups will have the greatest chance of success. Along with the appropriate academic and technical skills, students need to develop the social skills necessary for engineers to work in cooperation with technicians, management, and other engineers.

Personnel managers frequently state that 9 out of 10 of those who are fired from their jobs are fired because of their inability to work productively with other people. When companies spend time and money training engineers in social skills so that they effectively communicate with others, they are involved in educational efforts that would have been better provided to students earlier on. One of the ideas being promoted to assist the United States to be more competitive in the world market is "concurrent engineering." Concurrent engineering involves engineers working with other engineers. While our technology is arguably the best in the world, we often lack the ability to be able to use these technical skills to work together efficiently. The technology for the video recorder was developed in the United States, but we were not able to use this technology to produce a product faster, cheaper, or better than foreign competitors. One reason for this is our inability to organize our technical and production workforce to work cooperatively.

As a nation, we must strengthen the development of collaborative and social skills. This is evident not only in industry, but in the home and community as well. Stable marriages, family relations, and coworker relationships, require a complex set of social skills which must be learned as any other skill is learned. Cooperative learning focuses on the development of social skills while at the same time increasing the quality and efficiency of the work.

Many teachers and students have had experience with traditional group work. It is important to know that traditional group work and cooperative learning are significantly different. The difference is in how the teacher structures the learning goals. These determine the student to student interaction patterns, which are most powerful influences in the learning and working process.

A properly structured cooperative learning activity has five essential components:

1. **Positive Interdependence** - Students must feel that they need each other in order to complete the group's task, that they sink or swim together. Some ways to create this feeling are through establishing mutual goals, joint rewards, shared materials and information, and assigned roles. For example, when a team of students are solving the survival shelter

problem, the students have a mutual goal—they must come to an agreement on a design. Their tasks may be divided within the group so that each person has a job to perform. When completed, they will receive a group reward, which in this case may be a group grade. By setting these different types of *Positive Interdependence*, they will realize that they will succeed or not succeed as a group. They need to be concerned that everyone works together. They realize that they sink or swim as a team, not as individuals.

2. **Face to Face Interaction** - No magic exists in positive interdependence in and of itself. Beneficial educational outcomes are due to the interaction patterns and verbal exchanges that take place among students in carefully structured cooperative learning groups. Oral summarizing, giving and receiving explanations, and elaborating are important types of verbal interchanges. Students will have to discuss various problems and possible solutions with each other. They will have to talk out aloud about what they are thinking. It will be necessary for them to have a verbal dialogue with other group members.

3. **Individual Accountability** - Cooperative learning groups are not successful until every member has learned the material or has helped with and understood the assignment. Thus, it is important to frequently stress individual learning and assess it, so that group members can appropriately support and help each other. Some ways of structuring individual accountability are by giving each member an individual exam or by randomly selecting one member to give an answer for the entire group. When team members are responsible for particular sections of the case study report, for example, they experience the feeling that they cannot "free load" or let someone else's work represent their own.

4. **Interpersonal and Small Group Skills** - Students do not come to school with the social skills they need to collaborate effectively with others. So teachers need to teach the appropriate communications, leadership, trust, decision making, and conflict management skills to students and provide the motivation to use these skills in order for groups to function effectively. Part of every case study and every exercise needs to stress these skills which are essential for optimum group functioning. These are the skills that will enable students to use their academic and technical skills to work with other people to solve problems. Without these skills their technical skills are of little value.

5. **Group Processing** - Processing means giving students the time and procedures to analyze how well they are using the necessary social skills. This processing helps all group members achieve while maintaining effective working relationships among members. Feedback from the teacher and/or student observers on how well they observed the groups working may help processing effectiveness. Time needs to be spent at the end of every section of a case study to process the effectiveness of the team work and to make plans on how to improve the effectiveness of the group.

In addition to learning how to work cooperatively, Principles of Engineering students must also experience individual learning goals so that they can accomplish work on their own, and they must experience competitive learning goals, which when done properly, can stimulate and motivate groups for fun and excitement. Cooperative learning activities are the ones that should be used the majority of the time.

The skillful use of Cooperative Learning strategies does not come easily or quickly. Teachers need to be involved with methodology training and continued practice and support before they can expect these skills to develop. This process can take two or more years before cooperative learning strategies become internalized into the natural teaching method of the teacher. It is, however, worth the time and effort.

Adapted from: Johnson, D.W., Johnson, R and Holubec, E. (1986). Circles of Learning: Cooperation in the Classroom (revised). Edina, MN: Interaction Book Company.

I. SCOPE OF THE COURSE
The modules that compose Principles of Engineering constitute a one year elective course at the 11th and 12th grade level.

II. STATEMENT OF PURPOSE: GOALS
The course has been developed:

1. In response to national studies which suggest implementation of precollege courses that survey and stimulate interest in and access to careers in engineering and technology.

2. To explore the relationship among mathematics, science, technology, and engineering in an 11th/12th year course.

3. As a capstone course for students which integrates the study of math, science, and technology.

4. To enhance general technological literacy.

The goal of the course is to provide a one year introduction to engineering for academically able 11th or 12th grade students.

III. COURSE DESCRIPTION
The course is an integrative hands-on laboratory based set of case studies which will convey the concepts and principles, skills and techniques, and attitudes described in the sections on students outcomes.

IV. THE LEARNING ENVIRONMENT
The course will be taught in a laboratory setting providing access to tools and materials for individual, small group, and large group projects. Tools will include hand tools for wood, metal, electronic, and simple chemical projects as well as computers to be used for design, problem solving, as laboratory devices, and for control devices.

V. ORGANIZATION OF THE SYLLABUS
This syllabus is organized around a set of major concepts, skills, and attitudes that are generic and necessary to all engineering endeavors. These concepts, skills, and attitudes will be conveyed through a set of real-world case studies. Students will apply and reinforce these designed outcomes, therefore, within several different contexts

VI. THE CASE STUDY APPROACH
Real-world engineering problems are posed to Principles of Engineering students. These open-ended engineering problems are presented as case studies that cover a wide range of content. Each case study is of six to eight weeks in duration. Major engineering concepts are introduced at the beginning of the course and are reinforced throughout each case study.

The case studies include:

Auto Safety
Communications Technology
Energy (three case studies)
Machine Automation and Control
Shelter Design
Designing for People with Disabilities
(three 3-week case studies)

VII. STUDENT OUTCOMES: CONTENTS
A series of concepts generic to all branches of engineering have been identified. The concepts should be applied in the context of all the ***Principles of Engineering*** case studies. The major engineering concepts to be developed are design, modeling, systems, optimization, technology/society interactions, and ethics. Students are introduced to these concepts via short learning activities that are followed by engagement in the case studies.

1. **Engineering Design**
Identify needs and opportunities for solution by engineering means; gather information including reviewing prior attempts to solve similar problems; generate alternative designs; analyze what works and what does not, and examine tradeoffs; model prototypical solutions; and test the results, assessing the process and impacts on humans and the environment. (See MST Framework)

2. **Modeling**
Use mathematical models (e.g., charts, graphs, and equations), systems diagrams, and modeling hardware to design and build descriptive and functional models; explain the uses and limitations of physical, mathematical, and conceptual models; select and use simulation software to design, implement and test engineered systems. (See MST Framework)

3. **Systems**
Describe systems in terms of inputs, processes, outputs, and feedback/control mechanisms; explain and demonstrate how systems are comprised of interrelated subsystems; contrast open- and closed-loop systems. (See MST Framework)

4. **Optimization**
Apply algorithmic and trial and error techniques in making decisions; explain consequences involved in making trade-offs; consider criteria and constraints in real-world decision making situations; demonstrate use of cost-benefit and risk-benefit analyses in making decisions; use quantitative methods to analyze designs. **Note:** Costs include human, societal, political, environmental, and economic costs. (See MST Framework)

5. **Technology/Society Interactions**
Explain how engineering effects our values and world view and effects our knowledge base; explain why experts sometimes disagree about a course of action on social issues related to engineering; describe the various ethical positions in a controversial engineering endeavor; explain with specific examples, how engineering relates to other areas of study.

Describe alternative approaches to the solution of socio-technological problems, e.g., education (behavior modification), legislation (rules and laws), technological fixes (applying technology to the solution of a problem); take action in an effort such as lobbying, recycling, and/or developing a technological solution. More informed decisions can result from various aspects of the process of Technology Assessment. (See MST Framework)

6. **Engineering Ethics**
Consider the legal and professional responsibilities of contractual agreements and activities; exhibit social responsibility by considering benefits or risk to society, individuals, and the environment; assess long-term vs short-term risk and gains in making decisions.

Be aware of the moral dilemmas involved in employment, for example: do you blow the whistle on your employer even at risk of losing your job? How do you weigh the benefit vs the risk in making such a decision?

VIII. STUDENT OUTCOMES: SKILLS IN MATHEMATICS, SCIENCE, AND TECHNOLOGY

A series of broad-based skills has been identified that are transferable to many different engineering endeavors. These skills can be applied and refined as needed within the case study activities. The skills include: communication skills, skills in using technical tools, resources, and processes; measurement; and applying mathematics and science.

1. **Communication Skills**
Communicate in ways such as person to person, person to group, person to machine, and machine to machine; assist classmates as individuals, and while working in teams; present oral reports; program computers and computer-aided machines to solve problems and to communicate with another machine for the purpose of controlling its activity; present written reports that describe the engineering solution.

2. **Skills in Using Technical Tools, Resources, and Processes**
Use computer-aided design and drafting (CAD-D) software, computer simulations, application software, and computer hardware including interfaces for computer-aided manufacturing (CAM); develop skills in using hand tools, machines, equipment and instruments; access and

use sources of information including community-based resources, subject-matter experts, electronic data bases, and text. Select and process materials based upon their properties, cost, availability, suitability, and ease of disposal.

3. **Measurement**
Develop and refine skills in using various measuring devices to measure distance, area, volume, time, force, mass, velocity, and acceleration; calibrate measuring devices against known standards.

4. **Applying Mathematics and Science**
Develop and refine skills in mathematical problem solving, reasoning, communication, and connections among topics in mathematics and between mathematics and other disciplines; develop and refine skills in computation through estimation, use of calculators, and computers; develop and refine skills in scientific inquiry, and expand knowledge of science concepts and principles related to case studies (e.g., calculating heat loss through a material, calculating mechanical advantage vs velocity ratios in gear mechanisms.

IX. STUDENT OUTCOMES: ATTITUDES

Appropriate attitudes relative to professional and social obligations of the engineer, and relationships among science, technology and society should be inculcated through the Principles of Engineering course. By discussion and action students will demonstrate their understanding that:

A. Science, technology, and society interact.

B. Technology can be used to solve human problems.

C. Technology is part of a larger system. (Societal, Economic, Political).

D. Humans should use technology to their best long-term advantage.

E. Engineers must maintain high standards of ethical conduct and competence.

F. Engineers shall hold paramount the safety, health, and welfare of people, in the performance of their professional duties.

X. STUDENT ASSESSMENT

Student assessment will be accomplished through various means, including assessment of student performance on tasks related to the case studies; paper and pencil tests using questions related to the major concepts and content of the case studies; and discussions between the teacher and the student, and the teacher and student teams.

Students will be expected to keep a **Principles of Engineering Design Portfolio** which will document their efforts at finding and generating alternative solutions to the case study design problem. The design portfolio should include: the statement of the problem, investigative research and analysis, alternative ideas and designs, identification of the chosen solution and reasons for the choice, drawings and sketches, plans, and testing/evaluation procedures and results.

XI. THE CONCEPT/CONTENT MATRIX

As each of the case studies were developed the authors used a matrix of content vs each of the above concepts. For example, one of the content areas of the Machine Automation module was "Gear Mechanisms." In the gear mechanisms column of the matrix the various concepts were considered with suggested activities.

Engineering Design:
Design and build a gear mechanism that will transmit motion at right angles.

Modeling:
Build a simple gearbox.

Systems:
Explain the concept of gear ratio and compound gear transmission.

Optimization:
Explain the relationships among cost, speed, and strength.

Technology-Society Interactions:
Explain the effect of the automatic transmission on society.

Engineering Ethics:
Discuss the responsibility of auto manufacturers regarding the problem of transmission systems which "jump" from park to reverse when the car is parked with the engine running.

It is not necessary that each box in the matrix have an activity associated with it. By using the matrix the authors are able to ensure that each of the concepts is treated adequately enough so that students would be exposed to and involved in an activity which emphasized that concept. This system ensures that by the time the student has completed all five of the case studies he or she should be able to meet the complete set of performance objectives.

MAJOR CONCEPTS
Six major concepts, **Engineering Design, Modeling, Systems, Optimization, Technology-Society Interactions, and Engineering Ethics** have been identified as being generic to all engineering activity.

The following sections of the syllabus are designed to describe the major concepts (the principles of engineering) to be mastered through this course. Students should be familiar with the concepts before case studies are undertaken. Each concept is described and introduced through a series of introductory activities.

These concepts will be revisited within the context of each of the case studies.

ENGINEERING DESIGN

Engineering design is the process used by engineers to generate products, processes, and systems based on the recognition of societal needs. There are several factors that encompass engineering design. However, the following factors are of greater significance: functionality, quality, safety, ergonomics (human factors), appearance, environmental considerations, and economics.

FACTORS THAT AFFECT ENGINEERING DESIGN

Functionality: The product* designed must fulfill its intended purpose over its desired life span. For example, a light bulb manufactured to give 1000 hours of service. It is expected that the bulb will supply light for this period of time.

Quality: The product must be designed to meet at least certain minimum standards of value. Quality becomes extremely important within the pharmaceutical industry, in that the integrity of the medication produced must have the same formulation for every batch produced.

Safety: The product must be designed to comply with codes and regulations to provide for safe use and operation by the consumer. As an illustration, cooking utensils which are made of heat conducting materials, should have handles made of insulating materials.

Ergonomics: The product must be designed so that it can be operated with ease and maximum efficiency and maintained and serviced with a minimum of stress.

Appearance: The appeal of a product is based on the selection of materials, process, finish, color, shape, etc. When a car is purchased, several of the more practical factors such as functionality and ease of handling are considered, but ultimately the shape of the car, the paint finish, color, and style of the car are what sells it.

Environmental Considerations: The product must be designed so that it does not detrimentally affect the environment, e.g., polluting the air, etc. Regulations have been placed on the exhaust of internal combustion vehicles to reduce the release of carbon monoxides, lead, nitrous oxides, etc., to the atmosphere.

Economics: The product must be produced at the least cost to the manufacturer without impairing the safety of the public. Care must be exercised in this area. The quality of an object can be improved to the point of making it inaccessible to consumer at a reasonable price.

THE DESIGN PROCESS

Engineering design is an iterative process in which we proceed in a cyclical manner with constant feedback taking place as the design is defined. This sequence of steps progresses through (1) the recognition of a need, (2) the definition of the problem, (3) analysis of the problem, (4) the selection of an optimal design, (5) implementation or realization of the solution, (6) evaluation and testing of the design, and (7) presentation of the design. If any of these steps fail, the process must be began again from one of the steps that precedes it. For an excellent treatise on engineering design, see the article by Eric Thacher in Appendix C.

1. **Recognition of Need**
   Products created are a direct response to specific needs and wants of society. These needs can be immediate or futuristic.

2. **Definition of the Problem**
   All of the specifications (criteria and constraints) that affect the design of the product must be clearly stated, in a **design brief**. The design brief should not be more than a page long and should give concise details of the nature of the problem. It should give specific design constraints, such as the time available, the materials and equipment available, the environment in which project hardware has to work, as well as social and environmental considerations. **A carefully formulated statement of the problem can often save considerable time and energy.**

3. **Analysis of the Problem**
   With a clear definition of the problem the next phase is to generate possible solutions to the problem (brainstorming). It is suggested that the students generate at least three alternative solutions. When

***Product will refer to products, systems and processes.**

the solutions have been generated, these solutions should be documented in an outline. In completing this outline, the student should research all available data and illustrative material.

4. **Selection of a Solution**
   With the generation of possible solutions, generally an optimal solution must be selected and developed within an allotted time. The solution must be built using a modeling system with an explanation of the pros and cons of the design.

5. **Implementation or Realization**
   The components (parts, structures, equipment, etc.) required for the construction are obtained to complete the construction of a prototype of the chosen design.

6. **Evaluation and Testing**
   This is the final proof of a successful design. The prototype or model is tested for viability and quality. If the prototype fails the test, it may be necessary to make modifications and retest.

   A written, critical, evaluation should be made of the design, with suggestions for modifications, if necessary. If the project was not completely successfully, an analysis should be made as to why and suggestions offered to overcome or remedy the problem.

7. **Presentation**
   This is the crucial stage in the design process, in that, it involves the communication of the design to others. At this point, your idea is sold in a written, oral, and/or graphical format.

A CONCEPT MAP for showing the connections between the various components of the **Design Process** is shown on the next page.

ENGINEERING DESIGN:
INTRODUCTORY ACTIVITIES
SIX FACTORS RELATED TO GOOD DESIGN

1. **Aesthetics** - is the appearance of an object. It has to do with its form, scale, color, texture, and shape. An object which uses these elements well is said to be aesthetically pleasing.

2. **Ergonomics** - is often called "human factors engineering" because it has to do with design for humans and their environment. How well does a product relate to people's physical dimensions? A product that is ergonomically designed is comfortable to use.

3. **Performance** - is the design element which deals with the function of the product and how well it does what it is supposed to do.

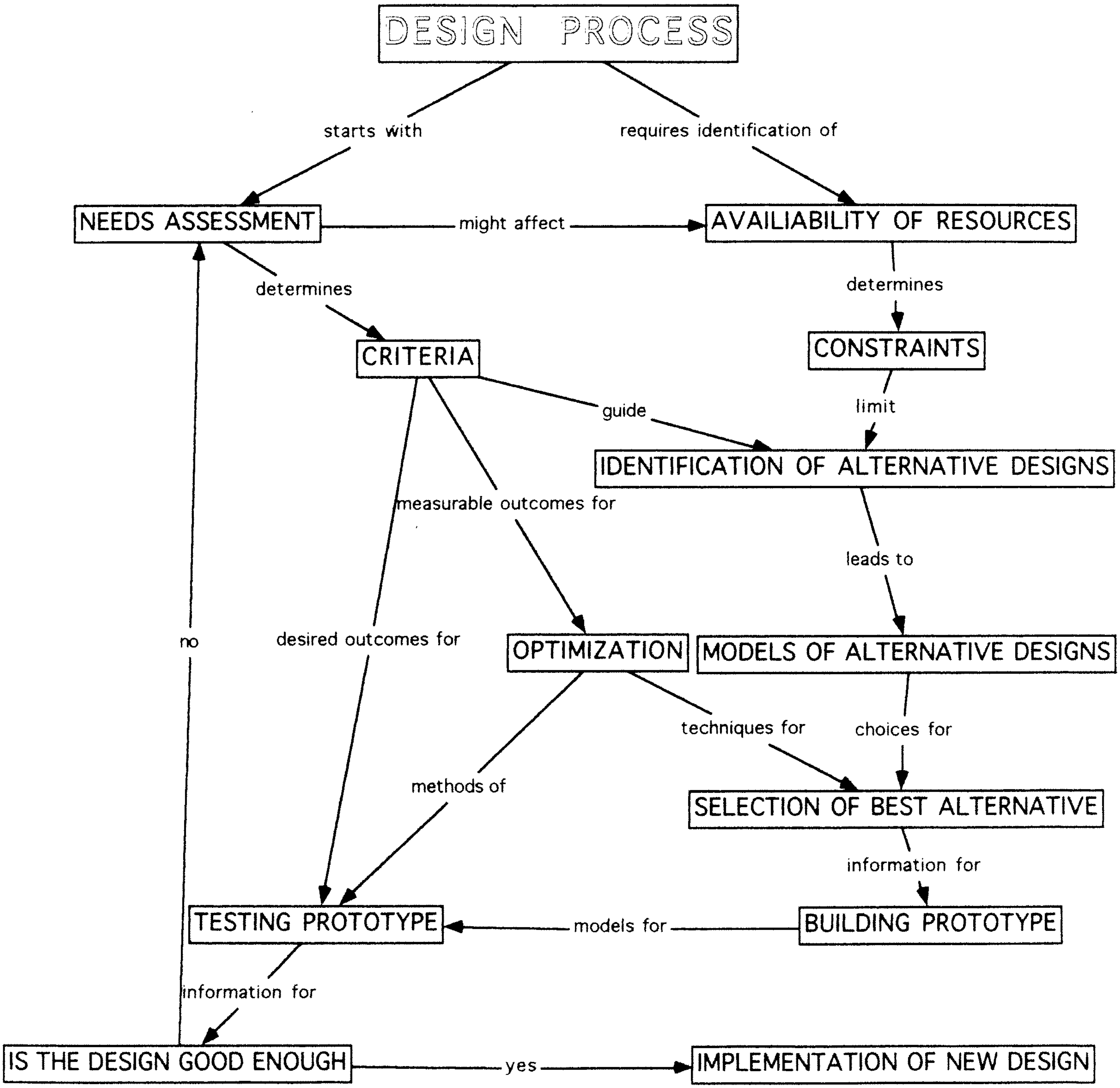
4. **Durability** - relates to the length of time a product will function correctly. It is usually associated with the product's purpose and its cost.

5. **Cost** - is what you get for your money. This is more than what you initially pay for the item. It also includes maintenance, (where applicable), energy to operate it, environmental considerations, (both in use and in clean-up at the factory) and guarantees. The disposal of the product should be figured into its cost.

6. **Suitability** - encompasses many qualities of a product, including its purpose, function, the materials from which it is made and the manufacturing process. Concerns for disposal of a product when its useful life is over are also important. Its impact on the environment and on the health and safety of the manufacturing worker as well as the operator are of prime importance in good design.

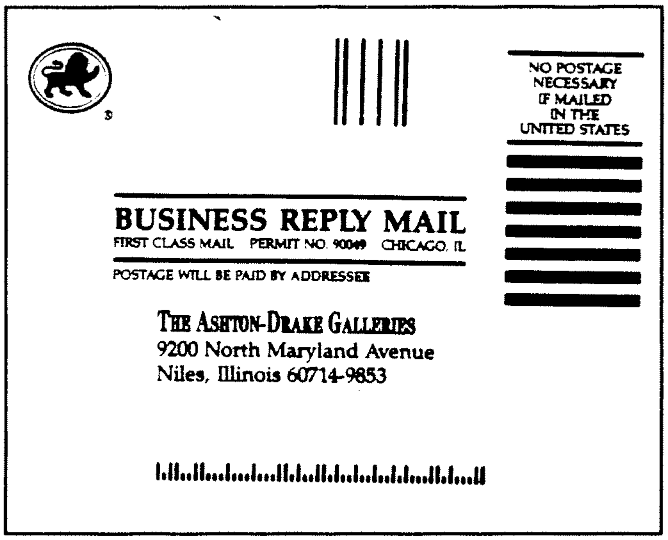
STUDENT ASSIGNMENT:
Use the above factors to evaluate common technological systems, such as bicycles, cars, and stereo systems.

CONCEPT MAP FOR DESIGN PROCESS



ACTIVITY ONE: Design of Bar Codes

The focus of this activity is on how bar codes are designed and used by the U.S. Postal Service to improve the routing of mail. You will try to crack the code that is used to represent the ZIP+4 code that is represented by the tall and short bars that are shown in the following sample business reply card:


NO POSTAGE NECESSARY IF MAILED IN THE UNITED STATES

BUSINESS REPLY MAIL

FIRST CLASS MAIL PERMIT NO. 90049 CHICAGO, IL

POSTAGE WILL BE PAID BY ADDRESSEE

THE ASHTON-DRAKE GALLERIES

9200 North Maryland Avenue

Niles, Illinois 60714-9853

CRACKING THE CODE

First, count the number of tall and short bars that appear on the bottom of sample card pictured to confirm that there are 52 bars. The machines in the post office that read the bars use the first tall bar as a **start** bar and the last tall bar as the **stop** bar.

The next task is to figure out how the remaining 50 bars are used to represent the nine decimal numbers of the ZIP+4 number (60714-9853). The first question is, how many bars are used to represent each decimal number? Notice that the nine numbers do not evenly divide into 50. Research into the operation of bar code systems will reveal that a tenth number, called a check digit, is included to allow the scanning machine to check for errors.

Since the 10 decimal numbers are represented by 50 bars, each number is coded by five bars. The machine reads the tall bar as a binary one (1), and the short bar as a binary zero (0). Your challenge is to figure out how the bar code system works by filling the following chart. Use a business reply card that contains a ZIP+4 number that contains a two to check if the predicted code for two is correct.

	Decimal Number	*Bar Code*	*Binary Code*
	0		
	1		
Predict	2		
	3		
	4		
	5		
Example	6	STTSS	01100
	7		
	8		
	9		

CHECKING FOR ERRORS

To find out how the check digit is used, add up the nine decimal numbers of the ZIP code and compare the sum to the check digit. Your next challenge is to figure out the **rule** that is used by the scanning machine to check for errors.

Hypothesis for rule is: ______________________________

____.

Use data from a number of cards to check if your hypothesis is right.

Next, inspect the binary codes for the 10 decimal numbers. See if you determine a common property of all 10 codes. How can this common property provide a second method to check for errors during scanning of the code?

____.

Both methods of error detection are possible because we are providing the machine with more information than is needed to code the ZIP code. For example, the check digit is an extra number. What about the binary code? Are five binary digits (bits) needed? Can we code 10 decimal numbers with less number of bits? Information scientists use the term *redundancy* to describe the use of the extra information used in bar code systems. For example, the UPC (Universal Product Code) system used by supermarkets uses even more redundancy (seven bits used, used to represent each decimal numbers).

What is the minimum number of bits needed to code 10 decimal numbers? ____________

Why? ____

____.

TEACHER'S GUIDE: Designing Bar Codes

	Decimal Number	Bar Code	Binary Code
	0	TTSSS	11000
	1	SSSTT	00011
Predict	2	SSTST	00101
	3	SSTTS	00110
	4	STSST	01001
	5	STSTS	01010
Example	6	STTSS	01100
	7	TSSST	10001
	8	TSSTS	10010
	9	TSTSS	10100

After students have had the opportunity to crack the code, the class can compare their results and answers to the question on the worksheets to the above chart.

CHECKING FOR ERRORS

To find out how the check digit is used, add up the nine decimals numbers of the ZIP code and compare the sum to the check digit. Your next challenge is to figure out the **rule** that is used by the scanning machine to check for errors.

Hypothesis for rule is:
Sum + check digit = Sum with a zero as the least significant position.

Use data from a number of cards to check if your hypothesis is right.

Next, inspect the binary codes for the 10 decimal numbers. See if you determine a common property of all 10 codes. How can this common property provide a second method to check for errors during scanning of the code?

All the codes have two ones and three zeros.

Both methods of error detection are possible because we are providing the machine with more information than is needed to code the ZIP code. For example, the check digit is an extra number. What about the binary code? Are five binary digits (bits) needed? Can we code 10 decimal numbers with fewer numbers of bits? Information scientists use the term *redundancy* to describe the use of the extra information used in bar code systems. For example, the UPC (Universal Product Code) system used by supermarkets uses even more redundancy.

What is the minimum number of bits needed to code 10 decimal numbers? *Four bits.*

REASON: With 4 bits, 16 different combinations of zeros and ones can be obtained. Since 10 decimal numbers need to be coded, having 16 combinations is more than enough.

ACTIVITY TWO: Example of Design Process

There is a need to protect and store Compact Disks.

1. Brainstorm designs for a device which will house a CD. It must protect it from breaking, being scratched, and gathering dust. It must also be economical to manufacture.

2. Identify the products currently on the market and those that have failed or were discontinued due to problems or cost.

3. List as many new ideas as possible to achieve the task.

4. Choose the best solution after examining the six factors in a good design.

5. Sketch some models of the storage unit.

6. If time permits, make a prototypical model of the case.

7. Evaluate your design against the criteria set out in the design brief. Indicate how the design could be improved.

STUDENT ACTIVITY:

Design a folder for Engineering Drawing. It must hold at least 10 drawings flat. It should be easy and attractive to carry in the halls. The drawings should be secure in the folder and it should protect against the rain.

Follow a procedure similar to that above to brainstorm, sketch, choose, prototype, and evaluate your design.

MODELING

Models of systems are needed to search for optimum solutions to decision-making problems. First, models are used to determine the seriousness and need for studying a problem. After criteria and constraints of a design or management problem are specified, models are used in the development and evaluation of alternative solutions. Finally, models are often used in the optimization process.

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

I. Descriptive Modeling
II. Functional Modeling

I. DESCRIPTIVE MODELING

Many techniques can be used to describe the static and dynamic behavior of systems. Methods for describing the relationship(s) between components and related parameters include:

1. Pictorial modeling results in descriptions that take the form of flow charts, block diagrams, maps, and other types of descriptive drawings.

2. Verbal modeling produces descriptions that use words to describe the behavior of systems.

3. Mathematical modeling produces graphs and equations that relate the parameters of interest within a system.

4. Physical replicas or scale models of systems provide 3-D representations. Examples are models of buildings or large construction projects.

II. FUNCTIONAL MODELING

In order to study the behavior of systems, functional models are needed to determine how a system might behave under changing conditions. Models for studying how system output(s) might be affected by change of input(s) include:

1. Physical models or replicas of real systems with moving parts. These can be manipulated to study behavioral patterns.

2. Computer simulations that support "what-if" investigations of system behavior and revision of existing models.

ILLUSTRATIVE EXAMPLES

A common technological system that can be used to provide examples of the use of various types of models is the automobile. Descriptive models: Pictorial models such graphs of car performance and block or wiring diagrams can be to show the structure of the suspension or electrical subsystem. Functional models: Prototype designs can be used to evaluate the performance of the car. Computer simulations used to test design ideas.

On the next page, there is a Concept Map that shows how various types of models are related.

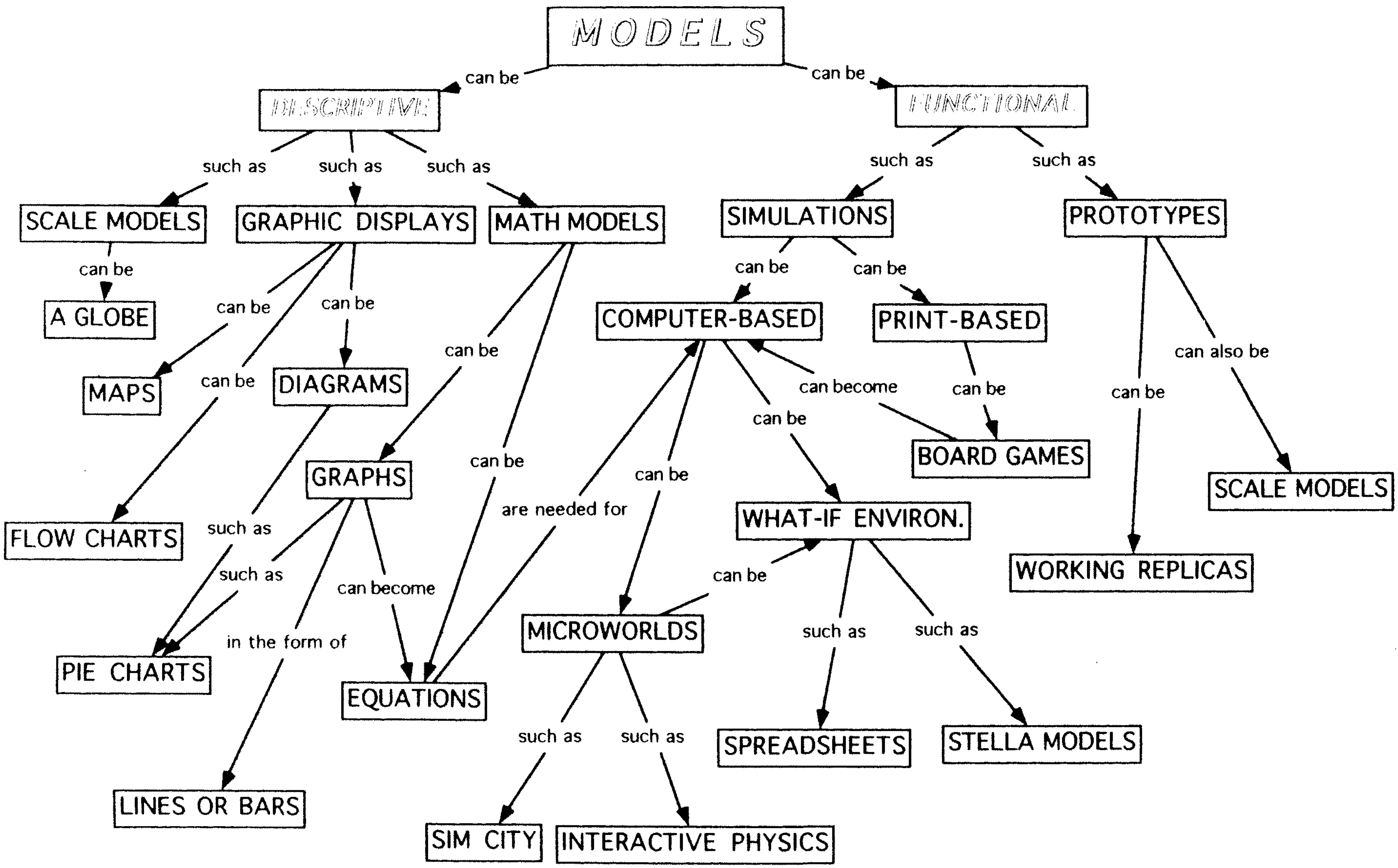
LEVELS OF UNDERSTANDING

When studying modeling concepts and skills a hierarchal structure should be used. There are four primary levels of understanding, namely:

1. **Comprehension** of information presented in or generated by models. This level includes the ability to **translate**, **interpret**, and **extrapolate** information from models. For example, given a table of how gasoline milage is affected by driving at different speeds, students should be able to draw a graph (translate) and determine the gasoline mileage when driving at different speeds (interpret). Students should also have the ability to estimate the gasoline mileage for speeds beyond those depicted on the graph that was produced using the information from the data table (extrapolate). Extrapolation beyond a limited range can result in erroneous predictions.

2. The next level is the **application** or use of models in specific concrete situations. For example, in planning an automobile trip the driver might be interested in conserving gasoline. The gasoline mileage vs speed graph combined with other information such as speed limits would help the driver figure out the optimum driving speeds for saving gasoline.

CONCEPT MAP FOR MODELING



3. The third level of understanding is the ability to use new information to **revise an existing model**. For example, students using a computer simulation to study the performance of different automobiles should be able to change vehicle parameters, such weight and drag coefficient to adjust the model to match the characteristics of a specific vehicle.

(4) The highest level of understanding is the ability to **create models** that describe or simulate the structure/behavior of real systems. For example, students interested in studying the effectiveness of seat belts in automobile accidents should be able to create scale models and simulated crashes.

MODELING: INTRODUCTORY ACTIVITIES

Many systems have similar growth patterns. Money in bank accounts, population of human or animal communities, and amount of solid waste generated in the USA are examples of systems that often grow exponentially. This type of growth is characterized by the fact that an increase in a specific time period is a percent of the amount at the end of the previous time period. For example, money in a savings account might earn additional money at a seven percent per year interest rate. In the simple case where the interest is compounded yearly instead of daily, a $1000 principle will earn $70 after the first year and will double in about 10 years.

The study of systems that grow exponentially is an excellent way of introducing students to the various methods of modeling the behavior of dynamic systems. Students can use data, such as the population growth of the world, and see how tables of population data can be displayed as different types pictorial models. After students develop understanding of the graphs associated with exponential growth, they can learn different ways modeling this type of growth by equations. The equations can also be used to develop a computer spreadsheet model of the system so that the effects of changing system variables can be studied. Computer software, such as "Car Builder" can be used to illustrate the use of a functional model.

ACTIVITY ONE

Introduce the "rule of 72" as a model for calculating the time necessary for a quantity to double when growing at a constant rate (72/percent growth rate). For example, a $100 bank deposit with a six percent compound interest will double in 12 years. Students can check this out with a simple calculator. First, input the growth rate. Two percent is represented as 1.02. Multiply this by the original quantity, and push the equal sign as many times as necessary to get a final total of twice the original amount. (Each push of the equal sign represents a unit of time.) In the case of the example of two percent, the total after 36 pushes is 2.04 times the original. Using a growth rate of nine percent, the total after eight pushes is 199 (72/9 = 8). As students try this model for other percentages, they will find that the model works well as an approximation for growth rates between 2 percent and 12 percent. Percentage rates of 2, 3, 4, 6, 8, 9, and 12 evenly divide 72. Rates of 5, 7, and 10 evenly divide 70. Have the students record the quantities for each of the time units and graph the data.

ACTIVITY TWO

Provide students with population data for the past hundred years and have them generate graphs and other types of pictorial models. Next, ask students to explore how they might use their models to forecast future population levels.

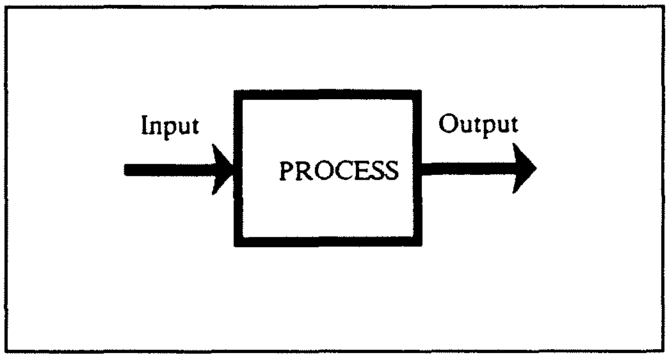
Have them extrapolate their graphs for the next 1,000 years and discuss the factors which might render that extrapolation invalid.

ACTIVITY THREE

An average high school student views television five hours a day. Much of their viewing, (four hours), are shows like MTV (2.5 hours) or situation comedies. Often a student will turn the TV on and only listen to it while he or she is busy doing something else (1.25 hours during MTV and .25 hours during sitcom). Generate a graph depicting the information, given above over a two-week period of time. Next, model a system for a more organized method of viewing. Use as many modeling methods as you feel necessary.

SYSTEMS

A system is a means of achieving a desired result. It has input, a process, output, and feedback. The input to a system is the desired result or the action you want to achieve. The process represents everything performed in and by the system. It is how the system will achieve the desired result. The output is what the actual result is and what the process produces. The output as feedback is compared to the input to achieve control.



The systems approach can also be considered a way of thinking. If you treat a problem as a group of systems and break these systems down into smaller subsystems it will simplify your problem-solving approach. In order to solve a problem you first have to define it. Once the problem has been defined you may then set your goals for the desired results. To achieve these goals, one should develop alternative solutions. Alternative solutions should be based on past experience, trial and error, insight, brainstorming, or accidental discovery. In the real world, optimizing alternative solutions often is done using modeling techniques. After optimizing the alternative solutions, you must choose the best solution and implement it. Once it has been implemented, there is a need for continued monitoring and evaluation. Also, one should be concerned with the risk, benefit, and trade-off when solving any large complex problem.

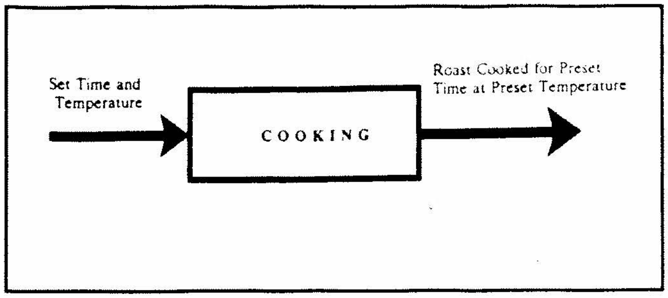
Technological systems can be found everywhere. They are all around us and even within us. The human body has many complex control systems. Within the functions of the human body there is an elaborate control system centered in the hypothalamus of the brain that maintains body temperature at 98.6 degrees Fahrenheit. This complex control system will maintain body temperature in spite of changes in physical activity and external ambience conditions. The human eye is also a control system. The diameter of the pupil automatically adjusts to control the amount of light that reaches the retina. Another control system, our sense of touch, also allows us to pick up an egg without fear of braking it.

Playing tennis and driving an automobile are two ways in which the human body functions as a complex controller. The eyes are the sensor that detects the position of the ball and the racket, or of the automobile and the center of the road. The brain acts as a complex controller which determines the actions that must be performed to accomplish the desired result. The body implements the control action by moving the tennis racket or turning the steering wheel; an experienced driver will anticipate all types of disturbances to the system, such as a rough section of pavement, or a slow moving vehicle ahead. It would be extremely difficult to reproduce an automatic controller that could take over the many judgments that an average person makes daily.

Heating systems regulate temperature in homes, schools, and buildings of all types. Control systems also affect the production of goods and services by ensuring the purity and uniformity of the food we eat, and by maintaining the quality of all kinds of manufactured products. Control systems help protect our environment. They minimize waste which reduces manufacturing costs and waste disposal problems. Sewage and waste treatment also require the use of automatic control systems.

A control system is any group of components that maintains some desired result or value. From the previous examples, it is clear that a great variety of components may be part of a single control system, whether they are electrical, electronic, mechanical, hydraulic, pneumatic, human, or any combination of these. The desired result may be, for example, the direction of an automobile, the temperature of a room, the level of liquid in a tank, or the pressure in a pipe.

An open-loop control system does not use a comparison of the actual result and the desired result to determine the control action. Instead, a calibrated setting obtained by some sort of calibration procedure is used to obtain the desired result.



An example of an open-loop control system is the cooking of a roast in an oven with a timer. We place the roast in the oven, set the cooking time. It is cooked for the preset time. Then remove the roast. The input to the control system is the time setting. The controller is the timer. It determines when the oven is to turn on and off by controlling the electricity to the heating elements. In this example cooking is the process and the actual cooking time for the roast is the output.

In a technological system the output may be controlled automatically by the use of feedback. Feedback is the action of measuring the difference between the actual result and the desired result. This is accomplished by the sensors. These sensors monitor the actual output of the system which is compared to the desired output. If the two are different, the controller will adjust the system to keep the actual output very close to the desired output. Systems that utilize feedback are called closed-loop control systems.

In the earlier example of cooking a roast, we can convert the open-loop system into a closed-loop control system by the introduction of feedback through the use of a meat thermometer (a sensor) placed in the roast. The roast will cook until the meat thermometer indicates the desired roast temperature and upon reaching this temperature the oven would then shut off. The external inputs to the system would be the starting time, the oven temperature and the desired meat temperature. The input to the controller is the difference between the desired and actual meat temperature. When this difference reaches zero the controller turns off the oven indicating the completion of the cooking cycle.

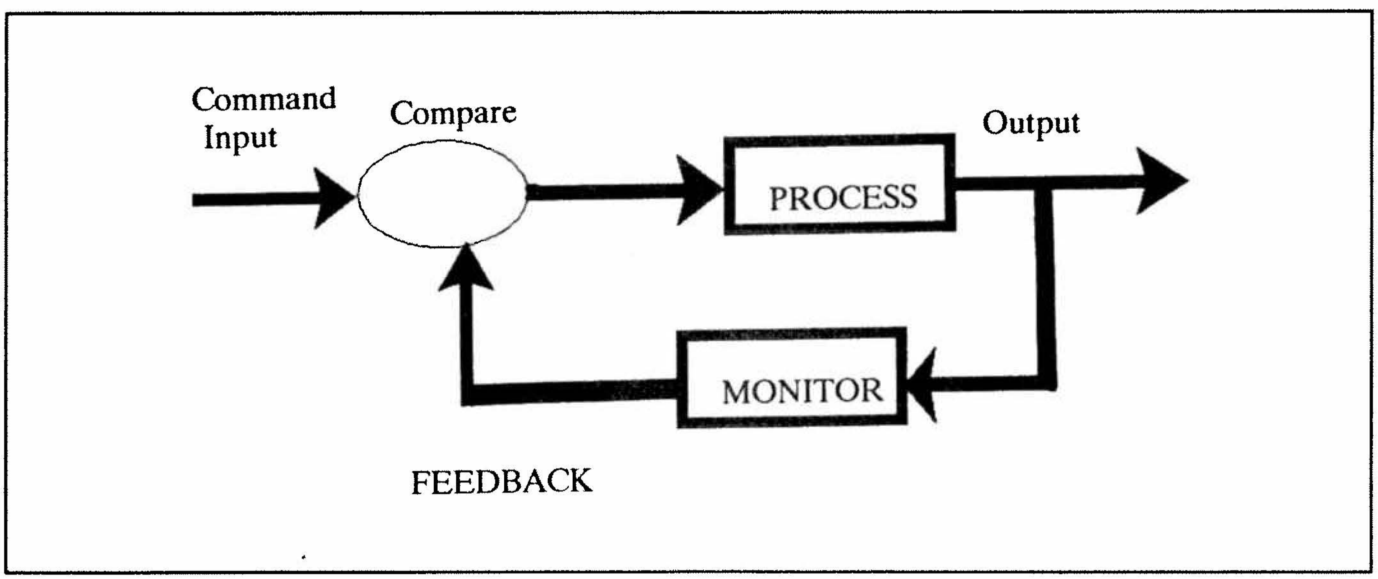
Systems are very important parts of our lives. We depend on them for everything from body control to communications. Thus, our goal is really to understand systems enough to make decisions about how to improve them as well as too use them wisely.

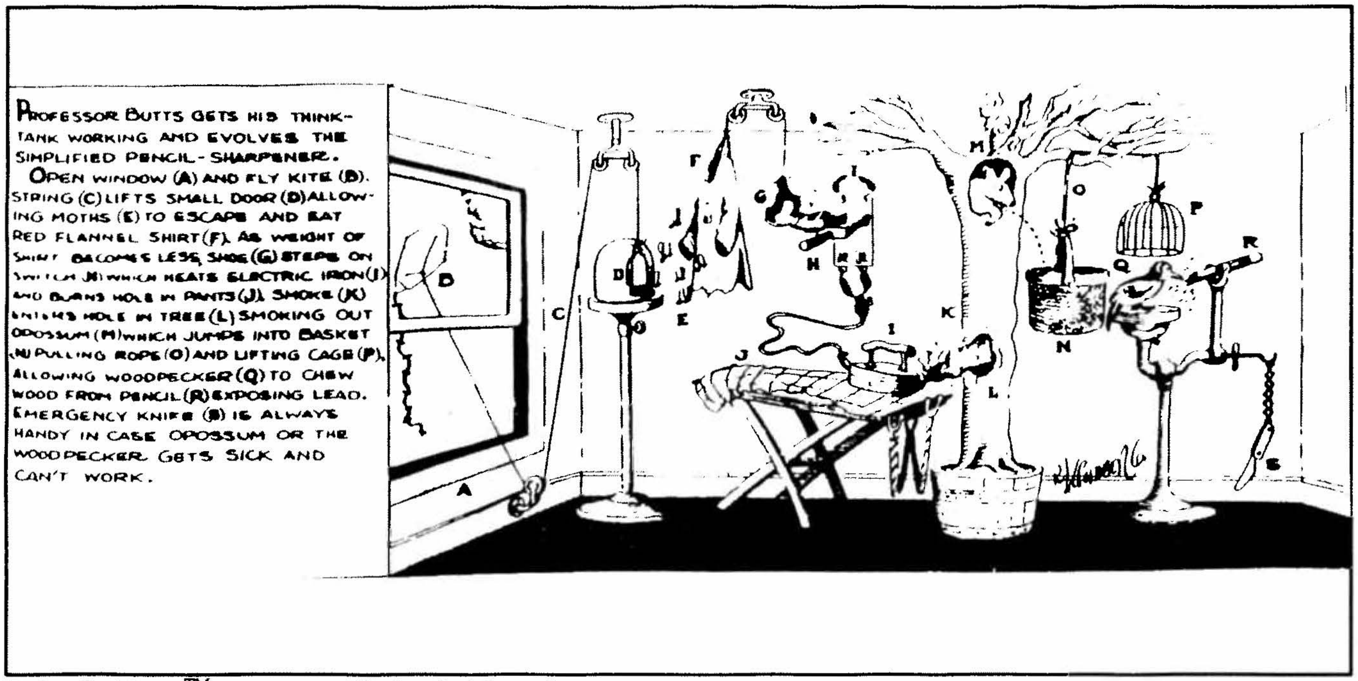
SYSTEMS: INTRODUCTORY ACTIVITIES

Analysis and Design of Rube Goldberg™-type Systems

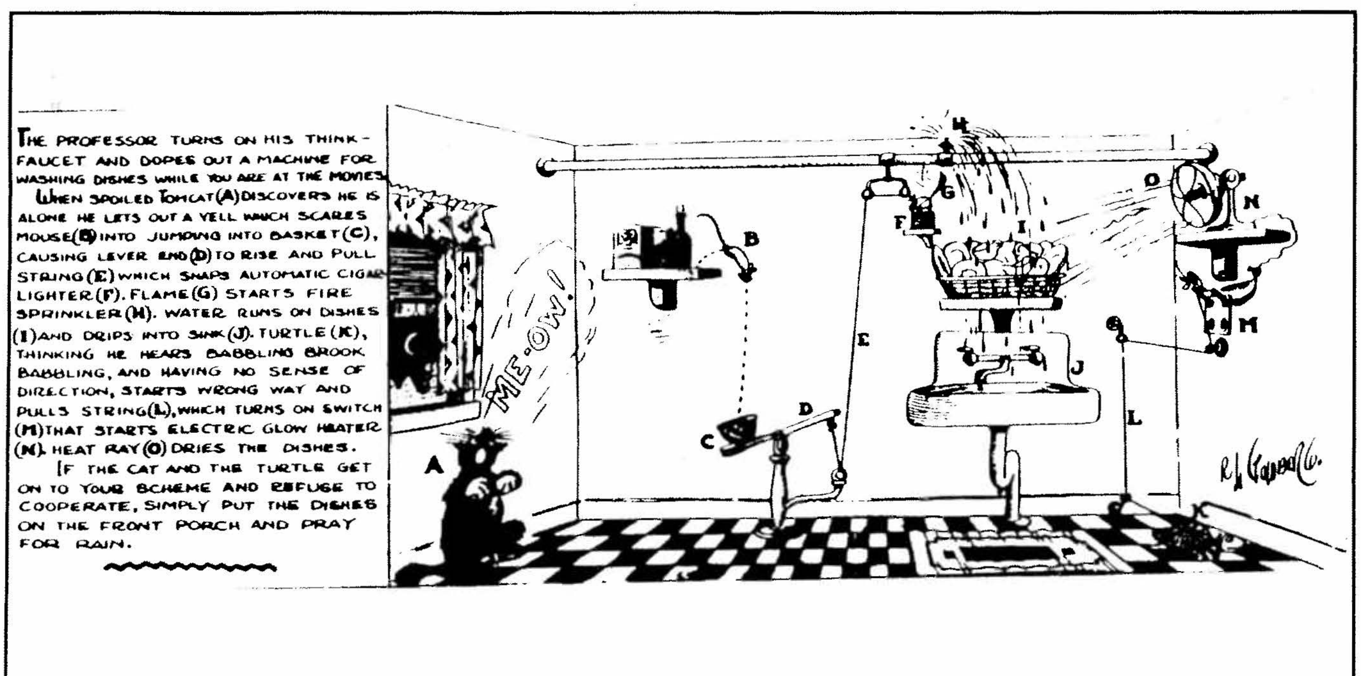
Break up into small cooperative learning groups. Discuss each student's role in the group and how he/she intends to approach this activity. Refer to the **Cooperative Learning** section on page 3.

Review the Rube Goldberg™-type cartoons on the following pages.

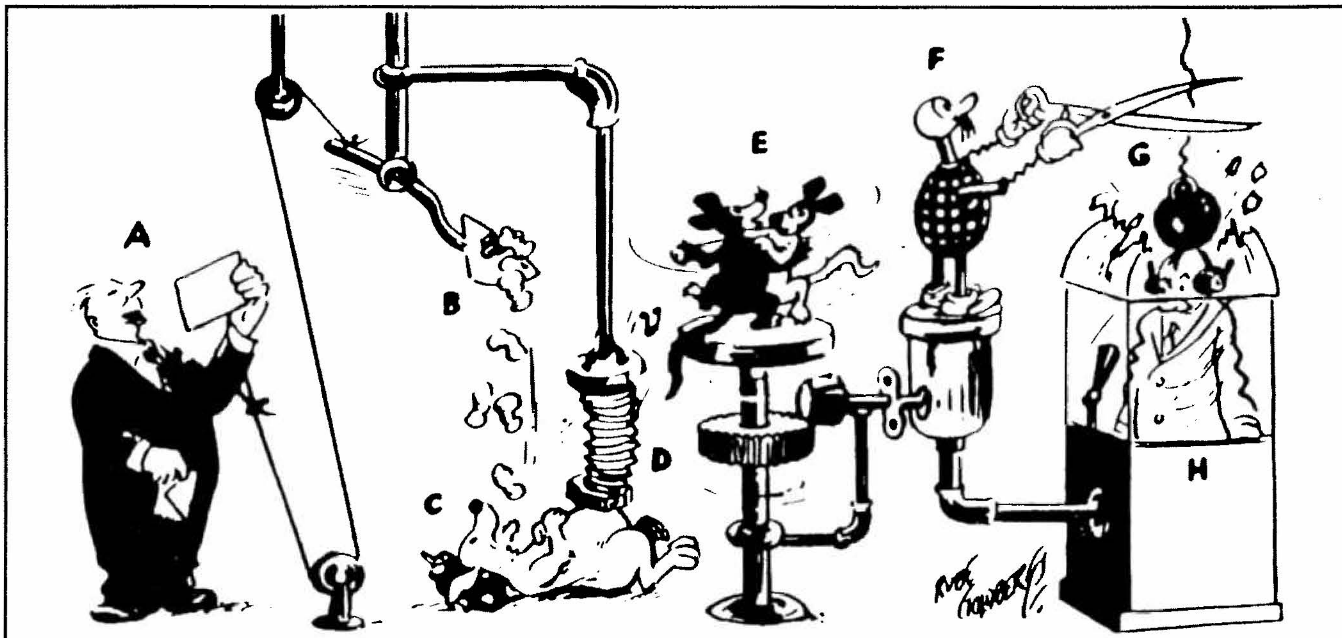




Rube Goldberg™ property of Rube Goldberg Inc.



Rube Goldberg™ property of Rube Goldberg Inc.



QUIZMASTER (A) RAISES HAND TO READ QUESTION, DROPPING SHOVELFUL OF DOG BISCUITS (B) INTO MOUTH OF RECLINING DOG (C) — DOG GOES TO SLEEP FROM OVEREATING AND HEAVY BREATHING PLAYS DANCE MUSIC ON ACCORDIAN (D) — WALTZING MICE (E) REVOLVE VIOLENTLY, CAUSING MECHANICAL BARBER (F) TO CUT STRING, DROPPING IRON BALL (G) ON CONTESTANT (H), RENDERING HIM UNABLE TO ANSWER QUESTION, THUS KEEPING PROGRAM FREE FROM CORRUPTION.

TEACHER'S GUIDE TO SYSTEMS ACTIVITIES

ACTIVITY OVERVIEW:

Understanding Complicated Systems

This activity uses an adaptation of a "Rube Goldberg™" cartoon to introduce students to input-output analysis. By recognizing how subsystems of a complicated system interact, students can begin to understand the operation of more complex machines such as computers or automobiles.

Materials

Copies of student activity sheet and pencils.

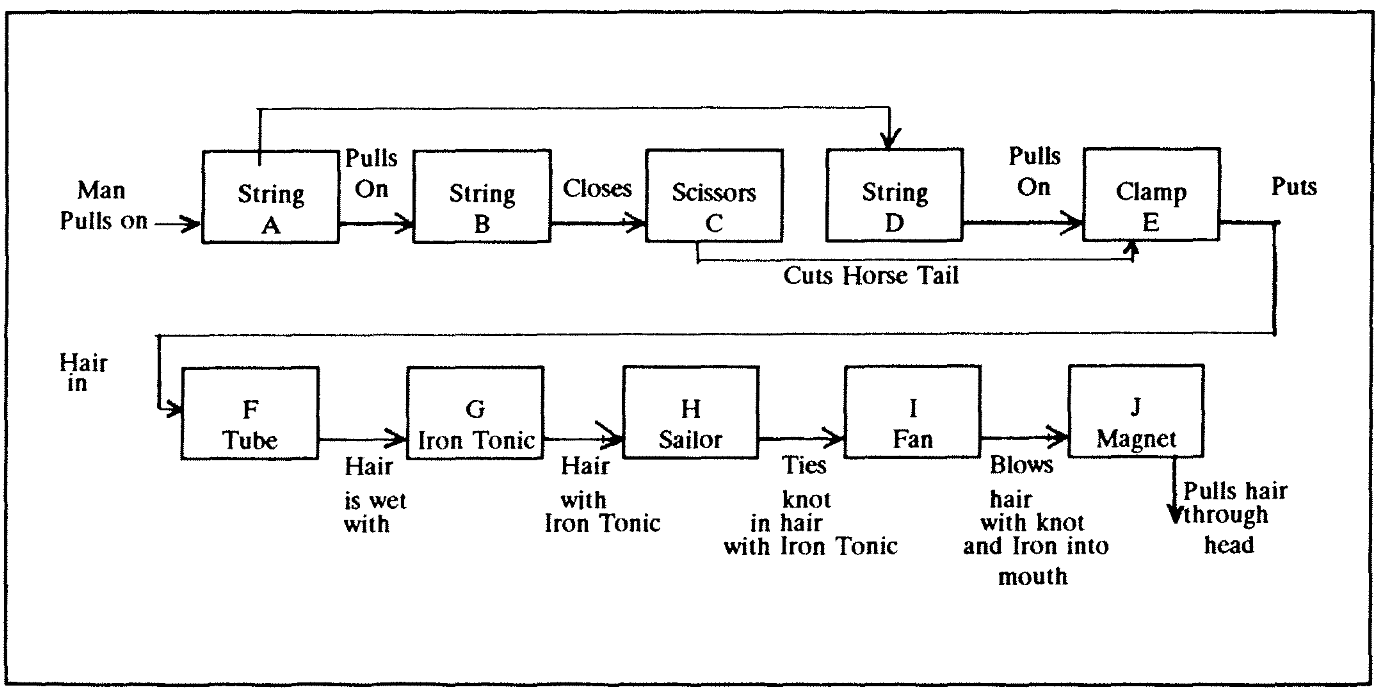
Instructional Strategy

After youngsters make an educated guess about the function of this Rube Goldberg™ system, have them work in cooperative learning groups to identify each of the 10 subsystems in the cartoon. Remind students that each subsystem has a specific purpose. Ask each student group to fill out the flowchart and explain how the 10 subsystems work together to achieve the ultimate purpose of this machine.

Besides providing an introduction to the input-output approach to systems analysis, this activity also provides a concrete example of the concept that "design follows function." The designer created this complicated machine as a whimsical way to grow hair. The filled-in flowchart at the bottom of the page provides a description of what the designer had in mind. Students will have the greatest difficulty figuring out the function of subsystems G and H. One way to help them is to suggest that they work backwards. In order for the magnet to attract the hair, it needs to be coated with iron, the substance in the vial at point G. The sailor ties a knot to prevent the hair from going through the head.

Extension

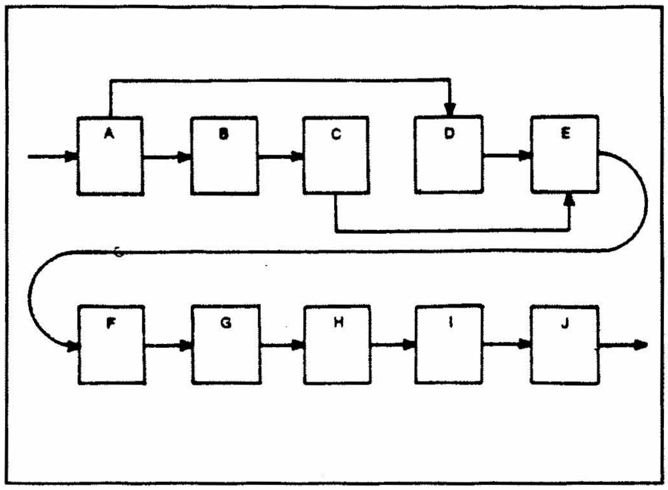
Ask students to identify major subsystems of a digital computer and draw a block diagram to show how the subsystems interact to process information.

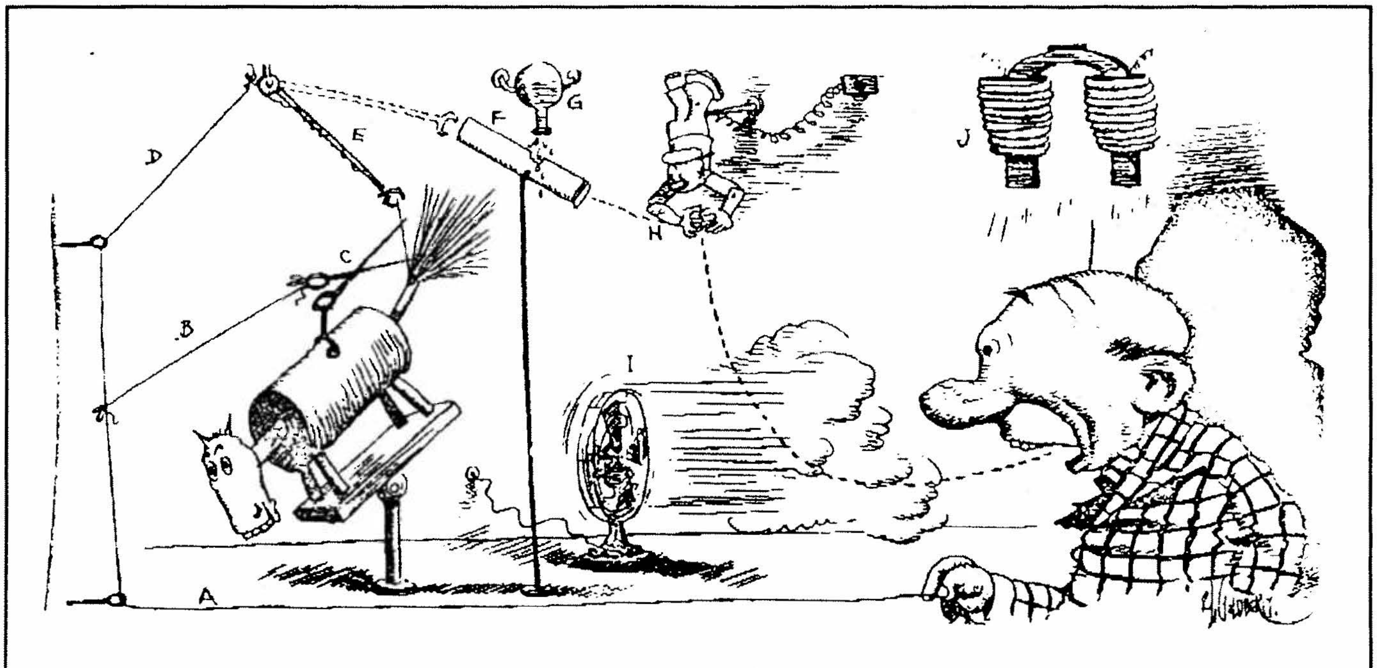


ACTIVITY ONE: Understanding Complicated Systems
Use this worksheet to analyze a Rube Goldberg™-type systems. Identify the subsystems and how they are connected. Using this worksheet as a model, ask students to analyze several other Rube Goldberg™-type systems in a similar manner.

The cartoon below was drawn by the famous illustrator, Rube Goldberg™. Can you figure out how the parts of his complicated machine work together to do a job?

Use the diagram to help you figure out how this machine does its job.





Rube Goldberg™ property of Rube Goldberg Inc.

The above complicated machine system is made up of 10 subsystems. Make an educated guess (hypothesis) about the *purpose* of this Rube Goldberg™ device.

Test your hypothesis by analyzing how the 10 subsystems work together to achieve the desired result. Try working backwards, it might help.

ACTIVITY TWO

Each group needs to solve the following Rube Goldberg™ -type problem. *How can one wake up a high school-age student in the morning?* Draw your ideas on a large size paper, use color to display your work. Each student in the group should contribute and draw his or her ideas. The problem can start anywhere but it must terminate with waking a student. Once complete, the group will present its design to the remainder of the class. The other class members must try to interpret your ideas in their order of occurrence. It is recommended that each idea be labeled in the sequence it transpires.

For Student's Use.

ACTIVITY THREE

Go back to your groups and change your Rube Goldberg™-type cartoon project from an open-loop to a closed-loop system. Include at least one redundant subsystem. Identify the feedback element(s) and discuss this design's superiority over the original drawing. Present the revised system to the class.

For Student's Use.

OPTIMIZATION is a key element in the decision-making process. It involves finding the best among all possible solutions—the solution requiring the fewest trade-offs. The optimization process contains three major elements:

Model: The most important aspect of modeling is the mathematical or quantitative description of the problem.

Criteria: The criteria are the goals or objectives of the decision-making problem.

Constraints: Constraints are added factors which must be considered in the solution of the decision problem.

Once the problem is formulated (the model), the engineer decides what is wanted (the criteria), and then what is permissible (the constraints), and is then ready to find the best, or optimum, solution.

Engineers must have an understanding of the technology of engineering: the levers, linkages, and screws that transmit power as well as the ways to control that power. In today's world, with a wide range of existing engineering resources, the choices of a design engineer are vast.

What guidelines are available if you want to develop the best possible design? Should you use a part that can withstand the greatest loads even though it might be the most expensive? Do operating and environmental conditions limit the choices to several competing possibilities?

Designers often come up against conflicting requirements. One consideration shows that you need more interior space, another that you need more structural strength, another that the structure should be collapsible and another that it be constructed by unskilled assemblers. The way to resolve these types of conflicts is called **optimization.** It is accomplished by assigning values to all requirements and selecting that design which maximizes (optimizes) the total value.

Engineers must consider economic costs. The device, product or structure must be produced at a low enough cost and at sufficient volume to recover all of the development expenses and produce a profit. In implementing civil engineering or space exploration, projects engineers must know whether the public is committed to the funding of the project to let it begin and continue. Many engineering problems can be solved if enough financial resources are available. The question that always arises is, Who will pay the cost?

Selection of a certain design will depend upon which of the various schemes offered appears the most favorable as a result of optimization. Optimization is finding the best combination of certain variables that will maximize the desired results, such as appearance, weight, durability, selling price, service ability, quietness, or sensitivity. If all design variables can be placed together on a value scale, it is possible through the use of an algorithm[1], to pick out an optimum combination and to make a single selection from among the competing alternatives.

Design through optimization is not always a simple straightforward process, but a procedure of trial and error and compromise until a well-matched combination of components has been found.

During the design process, you will have developed a series of alternatives and sketches to illustrate the relative merits of the design. These sketches are used to make a finished drawing. Optimization takes place as the rough sketches of the design are refined as the engineer makes trade-offs and tries different combinations and methods to solve the problem in a logical way.

TRADE-OFFS:

As a design begins to take shape, a number of important decisions must be made concerning matters such as performance, reliability, production, maintaining ability, and availability.

Often risk-benefit trade-offs and cost-benefit trade-offs must be made. Unfortunately, improvement in the level of

[1] An algorithm is a step-by-step process for solving a problem, which can be descriptive (as in a recipe or procedure for mixing chemicals) or mathematical (like a computer program or mathematical equations).

performance or quality in one area often results in the decrease of performance or quality levels in other areas. For example, an automobile engine developed for racing at high speeds will lose quality and reliability and use in slow speed driving, such as encountered in city traffic. To resolve problems, compromises must be made. Engineers cannot determine these compromises until an interactive modeling process is developed and values given to the various design requirements. The modeling process and the resulting choices of values or ranges of values for the design requirements variables is referred to as trade-off analysis.

OPTIMIZATION: INTRODUCTORY ACTIVITIES
ACTIVITY ONE

INTRODUCTION:

Most design problems we face have no definitive answer. Most solutions are a series of compromises which in turn allow the product to function well. An engineer must assess all the parts of a problem and optimize each before the job is resolved.

This assignment will involve the use of materials as well as a simple mathematical algorithm. The procedure for developing a maximum area will be expanded to a problem involving the study of volume.

PROBLEM ONE

A chicken farmer has a hundred feet of fencing in his barn. He would like to designate a fenced-in area for his chickens. The farmer decides to limit his design to one of three simple geometric shapes: round, square, and triangular. What is the maximized (optimum) area that may be obtained by each shape? Use several methods to obtain a solution. For example, use the string, (to represent the fence) and graph paper to visualize the optimum area possible with each shape; or, calculate the optimum area of each using the following equations:

Area of a Square = Side^2
Area of a Circle = πr^2
Area of a Triangle = 1/2 Base x Height

Set up an algorithm for determining which shape provides the maximized (optimum) area regardless of the length of fence.

PROBLEM TWO

A candy company needs a new box for 100 one-inch (diameter) malted milk balls. Determine the smallest box possible to hold 100 candies. Is this optimum shape practical for this product?

ACTIVITY TWO
INTRODUCTION

The activity in this lesson is designed to demonstrate the optimization process practiced by design engineers. The students will select a powerplant for a small family vehicle based on certain design constraints and current resource practicality.

The design variables for this project will be determined by the teacher and students after classroom discussion and review of the lesson materials.

After completing this project, the students will realize that:

A. The optimization process is not straight forward and involves many combinations and trial and error procedures.

B. Values are given to various design requirements that allow the trade-off analysis to be calculated.

C. Optimization is a key element in the decision making process which contains modeling, criteria and constraints.

Materials/Equipment
- drawing paper
- rulers
- calculators
- optimization study sheet

PROCEDURE

A. The instructor will explain that the ordinary gas engine has been outlawed because it cannot meet air pollution requirements and an optimal solutions must be found from three potential engine designs: the gas turbine, the elective motor and the steam engine. The class and instructors will enter these designs in a Table and assign values to the design criteria.

TABLE 1 Design Variables	1 -10 (low-high) Importance Rating to Total Vehicle Design
1) Vehicle Weight	
2) Engine Type	
3) Aerodynamics	
4) Cargo Capacity	
5) Passenger Capacity	
6) Power Output of Engine	
7) Fuel Economy	
8) Ease of Maintenance	
9) Body Strength	
10) Visibility	
11) Vehicle Range in Miles	

B. The instructor will generate a list of design variables that will cause direct trade-offs on each other to take place.

Example:

1. Power Output of Engine / Fuel Economy or
2. Engine Type / Ease of Maintenance or
3. Cargo Capacity / Vehicle Weight

C. The instructor will then compare with the class the perceived importance of the listed design criteria to the trade-offs that must be made to accomplish the total vehicle design. For example, if power output of the engine is considered important (rating 8) and fuel economy is also important (rating 9) then what consideration must be made to accomplish this objective or do trade-offs in the design begin to occur.

D. Each student will then submit a design based on design variable importance showing basic vehicle layout and performance specifications.

TECHNOLOGY-SOCIETY INTERACTION concept can best be explained by separating it into two parts: Technology Assessment, and Decisions Based upon the Assessment.

1. **Technology Assessment**
   Technology assessment is a system for determining potential future interactions which might result from the introduction of a new technology (fax machines) or the continued use of a present technology (chlorofluorocarbons in refrigeration).

2. **Decisions and Actions Based on the Results of the Technology Assessment**
   These decisions and actions can be further divided into two parts; public policy decisions and actions, and private citizen actions.

   Public policy decisions are usually based on cost benefit analysis (CBA) and risk benefit analysis (RBA) resulting in recommendations for the development of legislation and/or educational programs as well as the implementation of technological fixes.

   The private citizen actions are voluntary actions based on an informed awareness or on imposed regulations. Examples of citizen actions are recycling of household waste, installation of energy saving technologies, lobbying for more action from the policy-makers, and change in life-style.

   While the system for developing a technology assessment should be taught as a separate part of the course, the recommendations for decisions and actions are included in every case study in the program.

The matrix, shown on the next page, is the beginning of the assessment of solutions to the auto safety problem. Solutions can be technological, legislative, or based on public education of drivers. Fill out the matrix as an activity preliminary to the **Auto Safety Case Study.**

TECHNOLOGY-SOCIETY INTERACTION: INTRODUCTORY ACTIVITIES LESSON ONE

INTRODUCTION:

Students need to formulate a thought process which compels them to assess technological products. They need to expand their scope beyond that which a product exhibits on the surface.

DEVELOPMENT:

Technology impacts on new and existing commodities and these effects need to be studied. Once decisions and actions are examined, the product can be built, discarded or modified. Two types of decisions associated with public policy are:

CBA - Cost Benefit Analysis
Does the cost justify the product?

RBA - Risk Benefit Analysis
Does the risk of building or maintaining the product outweigh the negative societal impact?

An Assessment Method

Is the technology a problem?
How did it become a problem?
What are some alternative "fixes" to the problem?
a. Educational Programs
b. Legislative (Laws and Regulations)
c. Technological Fixes

What are the possible consequences of implementing the technology or its alternative?

MATRIX FOR CATEGORIZING AUTO SAFETY TECHNIQUES

	Methods/Causes	Technological Fixes	Laws and Regulations	Education Programs	Purpose
← PRE COLLISION →	Drunken Drivers				← PREVENT ACCIDENTS →
	Poor Drivers				
	Unsafe Cars and Components				
	Poorly Designed Road Systems				
← POST COLLISION →	Primary Crash				← REDUCE SEVERITY →
	Secondary Crash				
	Emergency Medical System Capability				

ACTIVITY ONE
In 1956, Gordon Damby and James Powell from Brookhaven created the process of vehicle propelled magnetic levitation. Since that time, many groups have experimented with their findings. The German and Japanese governments expressed so much interest in the project that they legislated hundreds of millions of dollars to develop a new transportation system.

Using the information listed below, make a technological assessment of whether or not public funds should be spent to develop this new transportation system in the U.S.A. Work in cooperative learning groups.

1. Cheaper to run per person than any other mass transportation.
2. Potential to move faster than any railroad train in action.
3. Few, if any, moving parts associated with vehicle.
4. Will cost billions to develop a prototype vehicle and track.
5. Sends out strong magnetic field around vehicle and track.
6. If successful, would stress or put railroads out of business.

LESSON TWO: Is it Worthwhile to Continue the Search for Extraterrestrial Life?
(An Outline for Student Seminar and Debate)

First Meeting
- Overview of STS issue - student opinions.
- Discuss "Thinking About Thinkers in Space."
- What is the likelihood of contacting ETI?

First estimation - number of Earth-like planets 4×10^{11} stars x .5 single stars x.1 sun-like x.1 with planets x.1 Earth-like. Thus about 2×10^{8} Earth-like planets.

Questions: What other factors would affect the likelihood of receiving an intelligent radio message? (At least four other factors.)

- What is the best approach to conducting the search?
- Should the Federal government finance the research? (HRMS Project)
- What is the impact on society if SETI is successful?

Second Meeting:
Debate the issue using a PBS "advocates" approach (a courtroom model for debates)

1. Class will be divided into PRO and CON groups.
2. Each PRO and CON group will organize itself in three subgroups:
   a. Legal team (two people)
   b. Research team #1 (expert witness #1)
   c. Research team #2 (expert witness #2)

Each witness will provide a five-minute testimony and will be cross-examined by the opposition lawyer for three minutes. One of the lawyers for the PRO and CON sides will provide a two-minute introduction and the other lawyer will provide a four-minute summation. The teacher will serve as the moderator (judge) for the "advocates" style debate.

LESSON THREE: Then What Happens?
(A way of assessing what might happen as a decision is made.)
Decisions regarding the introduction of a new technology, a family regulation, choosing a college, etc., are often based only on the *immediate* advantages and disadvantages of that decision. We could run the risk of discarding a valuable asset or introducing a dangerous hazard. The following system demonstrates a method of looking beyond the immediate results of a decision. It can be used to help analyze the long-range effects of a decision. For example, suppose that a proposed regulation would

require that by the year 2005, 50 percent of all cars in New York be Zero Emission Vehicles.

Start out with a large sheet of newsprint. Have the recorder person in each group draw a circle in the center of the sheet and write a few words describing the decision. Ask yourselves, "What might result immediately as a result of that decision?" In each group, the participants suggest things that might result from that decision. Each of the new events are written in circles connected by single lines to the original statement. **These are first order connections to the original decision.**

Now, ask the same question about each of the first order events and record the answers. Connect these second order events by a double line to the first order event. On a scale of minus 10 to plus 10, rate seriousness of the effects of the **second order events**. Add up all the plus and minus values to decide how the original decision affects individuals, families, and society as a whole.

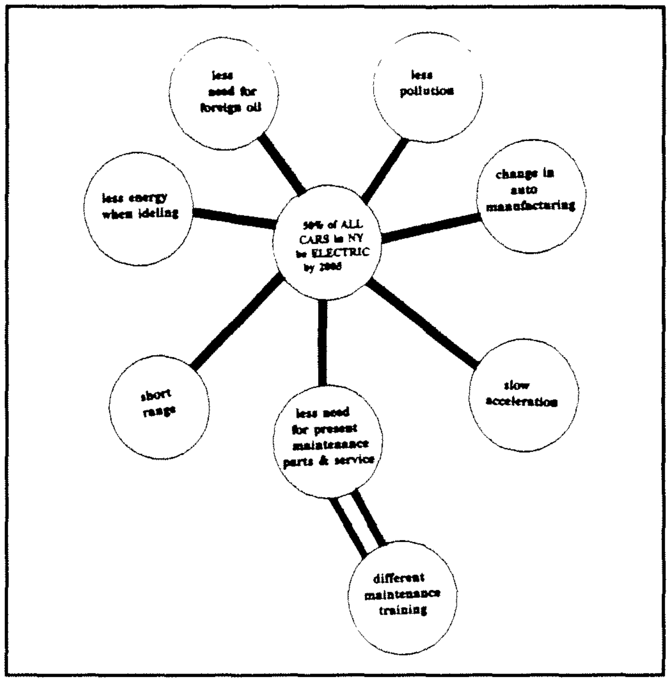
If time and understanding of probability permit, rate the probability of each second order event occurring, multiply that probability by the value assigned to the event and compare with the results of the first assessment.

During this activity, there will be many arguments as to the validity of connecting any one of the resulting events to the previous event, and many more regarding the numerical value and the probability of the event occurring as a result of the first order event, or even of the first order event happening. Where is the scientific evidence that leads you to that conclusion? What is the history behind your opinion? These are **Teachable Moments** when everyone is encouraged to look for more information on the situation.

A follow-up of this activity is to apply it to decisions regarding time spent on TV compared to homework, family rules, health habits, etc. The diagram can be used as a start for the analysis of a question similar to the one posed above. In this case, we analyze a decision to require the use of electric vehicles in order to meet the Zero Emission requirement. Complete the chart by adding more effects and rating the effects.

Then What Happens?

Identify some first generation effects and one second generation effect of requiring 50 percent electric vehicles by 2005. First generation (immediate) effects are connected to the decision with a single line. Second generation effects are connected to the first generation effects with a double line.



Remember: Rate the **second generation** effects from minus 10 for most detrimental to plus 10 for most beneficial. Add up all the pluses and minuses to decide whether it is a good decision.

ALTERNATE SCENARIOS FOR THE "THEN WHAT HAPPENS" ACTIVITY

A. All people who rollerblade must wear helmet, knee pads, elbow pads, and wrist supports.

B. No manufacturer may introduce any automated system until a plan for the training and employment of persons displayed by the automation is approved by the state labor relations board.

C. Every community which contains a shopping district or mall, must provide barrier free access to every business in the shopping district or mall, and ramps at every spot where a sidewalk meets a road.

D. Your State Department of Motor Vehicles is considering changing the minimum driving standard requirements for young adults. If the plan is enacted, a potential licensee will need to: (1) be a least 16 years-old and posses a valid high school diploma, or (2) be at least 21 years-old.

ETHICS IN ENGINEERING

Since the practice of engineering impacts on the quality of life for all people, high standards of ethical conduct and competence must be maintained. Engineers have professional and legal (contractual) responsibilities, and responsibilities that extend to clients, employers, coprofessionals, and to society-at-large.

PROFESSIONAL AND LEGAL RESPONSIBILITIES

As doctors adhere to the Hippocratic oath, so engineers adhere to guidelines for professional conduct. **Professional responsibilities** of engineers are outlined in Codes of Ethics written by professional organizations. According to Bill Middleton, chair of the IEEE Professional Ethics Task Force, "the contents of codes have significant bearing on how you handle issues" because the codes provide behavioral guidelines.

The core of the ethics codes adopted by AAES, ASCE, ASME, IEEE, and other professional associations, stems from an engineering ethics code drafted by the Engineers' Council for Professional Development (EPDC) in 1974. The latest versions of these codes state that "Engineers shall hold paramount the safety, health, and welfare of the public in the performance of their professional duties."

Legal responsibilities are those related to carrying out contractual obligations. Some engineers, who are in business for themselves as consultants, enter into direct contractual agreements with clients, and are legally bound to live up to the performance standards specified. Most engineers (unlike other licensed professionals like doctors, dentists, and lawyers), generally are not independent contractors. They often are company employees, and as such, are duty bound to act in the interests of the company and carry out its contractual obligations.

SOCIAL RESPONSIBILITIES

Engineers also have **social responsibilities**. Engineers, in the course of their work, must keep in mind that they must design and implement with a social conscience. According to Professor Deborah G. Johnson (Rensselaer Polytechnic Institute), engineers must "design for humanity." However, engineering design always involves some degree of risk; engineers have an obligation to inform their publics about the risks inherent in these designs. Risk/benefit trade-offs should be assessed on the basis of their impact on society, the individual, or the environment.

ETHICAL DILEMMAS

Engineers bear responsibilities to society, their profession, their employers, their families, and to themselves. When these responsibilities come into conflict, engineers are confronted by ethical dilemmas.

How should engineers react when faced with decisions that might place their own personal or professional values in conflict with those of employers or clients? Engineering decisions may involve making trade-offs that could save money or time, but such steps may cost human life, or reduce environmental quality. At what point do engineers stop increasing safety or quality, and accept an increased risk to human life or the environment, for the sake of keeping costs down? How much is human life or environmental quality worth?

The challenge of resolving such ethical dilemmas is a very real one for engineers. Individuals and companies must give ongoing attention to the resolution of ethical issues. If an employer or client is not willing to face and discuss ethical conflicts, the engineer has an increased challenge of where to go, and who to turn to in discussing the dilemma.

WHISTLE-BLOWING

Occasionally, tensions may result when engineers, who are loyal to the company and dependent upon company good will for compensation, promotional opportunities, and benefits, feel that there is a conflict between a company practice and their own social conscience. When an employee decides to notify someone outside the company about potential dangers or unethical behavior inside the company, this is called "blowing the whistle" on the company. The individual may report the issue to a newspaper, or to a regulatory agency in attempt to bring public pressure on the company to change its practices. Engineers may become "**whistle-blowers**" when they feel the company is not responsive to their concerns for the safety of people or the environment. Allan McDonald and Roger

Boisjoly, were engineers who worked for Morton-Thiokol. They questioned the O-ring seals on the Challenger rocket booster before the disaster. Both men were demoted by the employer.

Another instance of whistle-blowing occurred in 1972, in San Francisco. Three engineers, Holger Hjortsvang, Max Blankenzee, and Robert Bruder, expressed concerns about the safety of the Bay Area Rapid Transit (BART) system to the BART oversight board. Their concerns were dismissed, and the three engineers were fired. The press publicized the issue. The engineers claimed that they were adhering to their professional code of ethics which required them to hold "the public welfare as paramount."

Not long after, a BART train malfunctioned because of the problem pointed out by the engineers, and overran a station injuring passengers. The Institute of Electrical and Electronics Engineers gave an Award for Outstanding Service in the Public Interest to the three men.

Ethical dilemmas occur most commonly when engineers place schedules ahead of quality. Testing and inspection procedures provide assurances that products meet quality standards; but under pressure from supervisors to meet schedules, the engineer might consider elimination or curtailment of these procedures.

Whistle-blowing may seem to be the only way to bring attention to a problem if the employer or client refuses to acknowledge it. However, there are high risks to the individual whistle-blower. Whistle-blowers are usually seen as serious troublemakers and often suffer demotion, firing or even blacklisting within the industry. Corporations sometimes expect loyalty from their employees above all else. To question the judgment of an executive or manager is unfortunately seen as disloyal. Potential whistle-blowers must think very carefully about the risks they are incurring and the alternative ways they could affect change.

RESOLVING ETHICAL DILEMMAS

To help engineers **resolve ethical dilemmas**, companies can institute procedures that encourage employees to raise their concerns with management. Perceived problems may be reported through channels of communication that respect the engineer's anonymity. At McDonnell Aircraft, in Saint Louis, engineers have two routes that they can take. The first route is via the manager of the particular project that they are working on, for example, the F15 airplane project. The second route is via their functional manager; that is, a person who is an aerodynamicist would also report to someone with supervisory experience in his or her own discipline (another aerodynamicist, perhaps).

Raytheon Corporation in Lexington, Massachusetts, has gone so far as to name a Director of Corporate Ethics. The company has instituted policies that require employees to surface problems internally (within the company). The problems are investigated, corrected, and feedback is provided to the person who had originally raised the issue. The Director's objective is to make sure that the **corporate culture** (the ethical values of the company and the conduct and standards that guide workplace decisions) is communicated to all employees and suppliers. When company employees work within at atmosphere where problems are raised confidentially, and corrected, they are less likely to become disgruntled whistle-blowers.

Whistle-blowing has sometimes served to alert the public, and confront a company with a very real danger. However, it has clear detrimental effects on both the company and the individual. Although their conscience compels them to speak out, whistle-blowers do not usually become highly praised heroes. It is often difficult to get a job with another company once someone is labeled as a troublemaker by the employer. A few states have begun to enact legislation to protect whistle-blowers from losing their jobs.

It is in the interest of individual engineers, employees, and managers to learn how to recognize and resolve ethical dilemmas in the workplace. Creating channels for internal discussion of these issues is an important first step. In some companies an ombudsperson or ombudscommittee enables the individual to step outside the hierarchy of corporate authority to discuss the ethical problems in an unthreatening environment. This person or committee must have sufficient influence in the organization to resolve the problem.

Clearly communicating high ethical standards helps the engineer make these difficult decisions. If the corporate culture is such that regardless of the pressures, the corporation's reputation for quality and integrity is of paramount importance to them, engineers will be encouraged to surface ethical dilemmas and make more ethical decisions. In cases of questionable or faulty practices which engineers have been unable to change or influence, they may become whistle-blowers in order to uphold their obligations to the public and their profession.

CODE OF ETHICS

The Engineers' Committee on Professional Development (ECPD) developed a code of ethics for engineers which has become the core of codes adopted by other professional engineering associations. The code is as follows:

The Fundamental Principals

Engineers uphold and advance the integrity, honor, and dignity of the engineering profession by:

1. using their knowledge and skill for the enhancement of human welfare;

2. being honest and impartial, and serving with fidelity the public, their employees and clients;

3. striving to increase the competence and prestige of the engineering profession; and

4. supporting the professional and technical societies of their disciplines.

The Fundamental Canons

1. Engineers shall hold paramount the safety, health, and welfare of the public in the performance of their professional duties.

2. Engineers shall perform services only in the areas of their competence.

3. Engineers shall issue public statements only in an objective and truthful manner.

4. Engineers shall act in professional matters for each employer or client as faithful agents or trustees, and shall avoid conflicts of interest.

5. Engineers shall build their professional reputation on the merit of their services and shall not compete unfairly with others.

6. Engineers shall associate only with reputable persons or organizations.

7. Engineers shall continue their professional development throughout their careers and shall provide opportunities for the professional development of those engineers under their supervision.

ETHICS IN ENGINEERING: INTRODUCTORY ACTIVITIES

The following examples, submitted by Dr. Deborah G. Johnson, Department of Science and Technology Studies, Rensselaer Polytechnic Institute, reflect real work-related situations. In these cases, engineers have been presented with moral and ethical dilemmas. These cases can serve as role playing scenarios for groups in the class. Break up into cooperative learning groups and arrive at a group decision.

SCENARIOS

ACTIVITY ONE: "Protecting Public Welfare"

The XYZ Corporation has been advised by State Pollution Control Authority that it has 60 days to apply for a permit to discharge manufacturing wastes into a receiving body of water. XYZ is also advised of the minimum standard that must be met.

In an effort to convince the authority that the receiving body of water after receiving the manufacturing wastes will still meet established environmental standards, the corporation employs Engineer Doe to perform consulting engineering services and submit a detailed report.

After completion of his studies but before any written report, Doe concludes that the discharge from the plant will lower the quality of the receiving body of water below established standards. He further concludes that corrective action will be very costly. Doe verbally advises the XYZ Corporation of his findings. Subsequently, the corporation terminates the contract with Doe with full payment for services performed, and instructs Doe not to render a written report to the corporation.

Thereafter, Doe learns that the authority has called a public hearing and that the XYZ Corporation has presented data to support its view that the present discharge meets minimum standards.

Does Doe have an ethical obligation to report his findings to the authority upon learning of the hearing?

(From NSPE Opinions of the Board of Ethical Review Volume V, p. 7 Case No. 76-4.)

ACTIVITY TWO: "Falsifying Data"
Jay's boss is an acknowledged expert in the field of catalysis. Jay is the leader of a group that has been charged with developing a new catalyst system and the search has narrowed to two possibilities, Catalyst A and Catalyst B.

The boss is certain that the best choice is A, but he directs that tests be run on both, "just for the record." Owing to inexperienced help, the tests take longer than expected, and the results show that B is the preferred material. The engineers question the validity of the tests, but because of the project's timetable, there is no time to repeat the series. So the boss directs Jay to work the math backwards and come up with phony data to substantiate the choice of Catalyst A, a choice that all the engineers in the group, including Jay, fully agree with. Jay writes the report.

In the case above, Jay has written the report to suit his boss, and the company has gone ahead with an ambitious commercialization program for Catalyst A. Jay has been put in charge of the pilot plant where development work is being done on the project. To allay his doubts, he personally runs some clandestine tests on the two catalysts. To his astonishment and dismay, the tests determine that while Catalyst A works better under most conditions (as everyone had expected), at the operating conditions specified in the firm's process design, Catalyst B is indeed considerably superior.

What, if anything, should Jay do now?

(From Philip M. Kohn and Roy V. Hughson, "Perplexing Problems in Engineering Ethics" Chemical Engineering May 5, 1980.)

ACTIVITY THREE: "Conflict of Interest"
A government employee has a responsible position with a government engineering bureau. In the near future, the government bureau is planning to contract with one of three selected engineering firms; whichever appears to be the most capable of performing the work. At a social gathering one night, the government employee is approached by the head of one of the firms and told that if his firm receives the contract, the government employee could come to work for him at a considerable increase in salary. The government employee has been thinking of leaving government service because the office location is a long commuting distance from his home. He could leave and withdraw his retirement pay and purchase a small orchard which he has been looking at for several months. The orchard is only a short distance from the offices of the consulting firm, located in a suburban area.

The government employee makes no commitment to the head of the consulting firm but keeps thinking about the advantages of the change in employment. A couple of weeks later he is in a meeting with the government engineers responsible for the decision on which firm to select for the design work. The choice is narrowed down to two firms, one of which is the firm that made the covert approach. No decision is reached that day. They are all told to study the two proposals and then reach a decision with in three days. The government engineer is sure he can swing the decision to the firm which approached him by using mild persuasion on one or two members of the selection committee. He feels that both firms are capable of performing the design; in fact, it may be true that the firm from which he received the offer was in a slightly superior position.

He wonders if he should make a contact before the selection committee meets to see that the offer still holds and if so, to have a firm commitment on salary and position within the company and to be sure the company would wait six months so that no one would be suspicious.

What would you do if you were the government engineer?

(From D. Allan Firmange, Modern Engineering Practice. New York: Garland STPM Press, 1980. pp. 64-65.)

ACTIVITY FOUR: "Gifts to Foreign Officials"

Richard Roe, P.E., is president and chief executive officer of an engineering firm which has done overseas assignments in various parts of the world. The firm is negotiating for a contract in a foreign country in which it has not worked previously. Roe is advised by a high-ranking government official of that country that it is established practice for those awarded contracts to make personal gifts to the government officials who are authorized to award the contracts, and that such practice is legal in that country. Roe is further advised that while the condition is not to be included in the contract, his failure to make the gifts will result in no further work being awarded to the firm and to expect poor cooperation in performing the first contract. He is further told that other firms have adhered to the local practice in regard to such gifts.

Would it be ethical for Roe to accept the contract and make the gifts as described?

(From NSPE Opinion of the Board of Ethical Review Volume V, p.11, Case #76-6.)

DESIGNING AUTOS FOR SAFETY

Analysis of data regarding the causes of accidents and the injuries and fatalities which result from those accidents reveals that the major areas of responsibility are the driver, the vehicle, the road, and the regulations.

The approach to possible resolution of the auto safety problem is to examine various alternative solutions as they relate to the design of autos, roads, law enforcement technologies (i.e., police radar) and assess their feasibility, and their potential effect on the overall safety of travel by automobile.

The analysis of the various auto safety situations will involve the application of physical laws, mathematical analysis using graphs and simple algebra as well as discussion of ethical values.

The approach to possible solutions will involve measurement of force, acceleration, velocity, human reaction time, and hand-eye coordination. The design and construction of experimental apparatus will include the use of design skills as well as the use of hand and machine tools.

COMMUNICATIONS TECHNOLOGY

We use technology to improve our ability to communicate and transfer information in three modes:

- Human ⟷ Human Communication
- Human ⟷ Machine Communication
- Machine ⟷ Machine Communication

In this module, the focus of study is the ergonomics (human factors engineering) of communications technology systems. Thus, we will only study systems that deal with the first two modes of information transfer.

In designing technological systems, human factors engineers or ergonomists work to design systems that are *compatible* with human capabilities and limitations. These systems must satisfy eight primary criteria:

1. be safe to use;
2. be practical and easy to use;
3. be durable;
4. match their surroundings;
5. satisfy the needs of users;
6. be comfortable;
7. not disrupt working relationships or work routines; and
8. not lend themselves to abuse or misuse.

ENERGY CASE STUDY

Energy is at the heart of all that we do. Our own personal energy enables us to move, speak, and breathe. Entire bookshelves of written materials and whole courses and even careers are devoted to the study of energy.

This six- to eight-week **case study** will, of necessity, deal with a very small segment (three aspects) of the energy situation. Following a brief study of energy sources and transformation into electrical energy, students will examine the use of electrical energy in lighting and household appliances (Section A.) They then have the option to concentrate on one or both of the other two aspects of energy covered in this case study. Building a **Model Low Energy Use Home** (Section B.) or **Building a Model Solar-Electric Car** (Section C.) In each of the cases, the concepts of the syllabus: Engineering Design, Modeling, Systems, Optimization, Technology-Society Interactions, and Ethics in Engineering will form the basis of the activity.

MACHINE AUTOMATION AND CONTROL

The objectives of this case study are to encourage students to become familiar with, and understand some of the principles involved in, machine automation; to understand the importance of automation and control processes on our society; and to participate in an exercise in creativity. The design problem will require a student to design, draw, build, and test a machine automation project. After the project has been completed, students will have a new awareness of machine automation and control; and the importance it has in shaping our civilization and economy. Students will be introduced to the disciplines of mechanics, control engineering, structural design, pneumatics and hydraulics, and robotics. Schools, for this vital reason, should be providing students with an introduction to the fundamentals of these evolving technologies in an intensely practical way, through hands-on experiences and problem-solving applications.

How these technologies work and how they can be applied are the thrusts of this case study on machine automation. The emphasis is on gaining an understanding, in a totally practical way, of the physical sciences behind the technologies. Math and physics come alive to students when what has been abstractions are applied in real-life problem-solving situations.

The main focus of this case study is on conversion of energy, and transmission and control of power. It is not intended to produce "technicians" or "automation specialists." Instead, the students are being exposed to fundamentals on which such new jobs skills depend. This will be accomplished by combination of classroom theory and practical hands-on experience.

SHELTER DESIGN

Human-kind has been engaged in the building and designing of structures since the beginning of recorded history. The conquest of the environment and the ability to exist anywhere on the planet earth has allowed humans to create the technological wonders we now see as common place. The design and construction of structures is a knowledge built on thousands of years of practical trial and error study and application. The understanding of structures and the forces that act upon structures will be explored in this case study. A teacher-led discussion on a structural collapse (e.g., the two suspended walkways within the atrium area of the Hyatt Regency Hotel in 1981) as well as various demonstrations of structural principles should be covered as an introduction to the case study problem. The main focus of this study is on survival and how structures must protect human inhabitants in the most difficult of situations. The instructor will have the ability to diverge into structural forces, thermodynamics, energy loss and gain, packaging, ergonomics, instructional documentation, mass production considerations, and materials processing.

This understanding will be accomplished through a combination of classroom theory, library research, rough sketch and final designs utilizing CAD or Technical Drafting and hands-on experience of building a prototype model or full-size construction.

DESIGNING TECHNOLOGY FOR PEOPLE WITH DISABILITIES

This project is supported by a grant from the NEC of America Foundation. For more information contact:
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Overview of Project and Engineering Design Case Studies

- Designing Adaptive Devices
- Adaptive Radio-Control Car
- School Accessibility for Students with Visual Impairments

PURPOSE:
The main purpose of the DTPD (Designing Technology for People with Disabilities) project is the development of curriculum materials to engage all students in the design of technological systems to address the needs of students with disabilities. Besides developing engineering-based case studies, the project will also develop a teacher's guide to facilitate inclusion of all students into a "Principles of Engineering" course. Specifically, the two objectives of the DTPD project are:

1. Development of curriculum materials to be used with high school students participating in the "Principles of Engineering (POE)" course relating to technology for people with disabilities.

2. Researching and preparing a teacher's guide to facilitate inclusion of students with disabilities into "Principles of Engineering." This will include strategies and guidelines for encouraging participation by all students as well as specific guidelines to assure program accessibility for students with disabilities.

CASE STUDY ONE: Designing Adaptive Devices
Problem Definition:
This case study will introduce students to the process of designing an adaptive device for those who have disabilities. In the first scenario, the adaptive device will be a telephone. An adaptive device is defined here as: *a device that is not designed conventionally, but rather one that is designed for universal use by all people.*

Students will develop an increased awareness of the special needs of persons having a disability, and they will then incorporate this new awareness into their designs. The notion of universal design will be stressed in all of the student's work.

SCENARIO
A new grant project has been funded by Federal and state agencies to provide group housing for individuals with disabilities. This project, entitled "Independent Living," is designed to enable people with disabilities to reach their potential as productive citizens. This project is experimental, and it is funded to determine whether or not people with disabilities can live together on their own in a group home. The residents all have different disabilities and will need each other to function. They must help each other to overcome barriers within their environment. The residents in this group home will have limited means, and will all need to use a telephone. Their telephone must be adaptive/universally designed.

CASE STUDY TWO: Adaptive Radio-Control Car
Problem Definition:
This case study is a design problem which requires a team of students to adapt a remote-controlled toy car so that a person with specific physical limitations can operate the vehicle to a predetermined proficiency. The unit is designed to be a flexible, short-term unit which can be adapted to either meet time constraints or student's interest and abilities, or facilities and equipment. Students will be working with such concepts as scientific problem solving, simple electronic controls, mechanics of motion, human factors engineering.

SCENARIO
Three years ago, some friends introduced Sandy George to remote-controlled racing cars. After attending several competitions, Sandy soon became a participant and competitor. She entered several events and was beginning to gain recognition in her new found hobby when she had her skiing accident.

Sandy was informed at the hospital that she experienced a spinal-cord injury which would result in her having only limited use of her right hand and no mobility in her legs from the knees down.

After one year of rehabilitation, Sandy is very anxious to resume some of her activities, especially her hobby of R/C race cars. Her lack of finger dexterity prevents Sandy from using the standard control box.

CASE STUDY THREE: **School Accessibility for Students with Visual Impairments**
Problem Definition:
This case study is structured to acquaint all students with some of the challenges faced by students with visual impairments, by researching existing adaptive devices and by having students design new devices and/or design solutions to predetermined problematic situations. Students will work in teams and solve a series of problems, such as design of a signage system and an audio guide.

SCENARIO
Tommy is going to be a new student at your school. As long as he could remember, he wanted to be a veterinarian like his father. He loved accompanying his parents to the nearby farms, and watching his father's skillful hands. One day, all his plans were overturned when a speeding car knocked him off his bike. Without a helmet on, his head was unprotected. Tommy was brought to the hospital

unconscious and, when he awoke, his physician informed him that the accident had affected his eyesight and the full use of his arms and legs. These conditions have slowly improved with therapy and the 16-year-old has fervent hopes that he will eventually make a complete recovery.

Your team's task is to design and develop prototype systems to help Tommy get around more effectively when he starts attending your school.

USING ENGINEERING CASE STUDIES TO INTEGRATE THE STUDY OF MATH, SCIENCE, AND TECHNOLOGY*

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NEED FOR INTEGRATED MST LEARNING EXPERIENCES

"A common theme in the studies is that engineering is an integrative process and that curriculum innovation therefore should be toward this end."[1]

"Integrated learning outcomes must be emphasized in the goals of the new educational system; integrated because that is the real world. No subject in Mathematics, Science or Technology (MST) exists or is used in isolation from the others."[2]

A major problem of secondary mathematics, science, and technology (MST) education is that students usually learn subject matter only in the context of the specific disciplines. No wonder the majority of our students constantly ask: Why are we learning this? Students in science and mathematics courses seldom learn how the concepts that they are learning are applied to the design and operation of the technological systems that surround and affect them daily. On the other hand, students in technology courses often do not learn the science and mathematics concepts that underlie the systems that they are studying.

What is needed are learning experiences that are anchored in real world problems and environments.[3,4] Students learn best when instruction is provided in the context of problems and situations that are meaningful and of interest to them. Learning should also be related to the future adult roles that students will have to assume. In a report of a U.S. Department of Labor's SCANS (Secretary's Commission on Achieving Necessary Skills) Project, a primary recommendation is that functional and enabling skills should be learned in the context of situations that relate to the workplace.[5] Other studies and reports have recommended that instruction needs to be anchored in problems and settings that are related to relevant real world examples.

Given the need to provide integrated MST learning experiences, new learning standards and curriculum/instruction programs must be developed. This paper will next describe New York State's New Compact for Learning educational reform project and specifically discuss the work of the MST curriculum and assessment committee. The design and content of a new introductory high school engineering course will be presented as an exemplary program for helping students to achieve the new integrated MST learning standards.

NEW COMPACT FOR LEARNING

In March 1991, the Board of Regents adopted a New Compact for Learning, a comprehensive strategy for improving elementary, middle and secondary education results in New York State schools. One of the steps taken to accomplish this was the establishment of statewide committees to define general learning standards. In October 1991, the Curriculum and Assessment Committee for Mathematics, Science, and Technology was one of seven subject area committees established to carry out this task. Since that time, the committee has been discussing how to assure that all children graduate from high school with a basic literacy in mathematics, science, and technology, and how to provide the motivation and develop skills through the education system to enable more students to pursue careers in these disciplines. Basic literacy in mathematics, science, and technology is defined as that knowledge which is both necessary (a) for an adequate understanding of current societal issues which can impact

*This paper was presented at the 1994 ASSE Northeast Regional Conference that was held at Hofstra University.

the quality of life as well as (b) to maintain an awareness of future learning which must be acquired as these issues evolve based on new science and technology. The recommendations of the committee will represent the essential elements necessary for achieving literacy in mathematics, science, and technology and to encourage students with interest and capabilities to pursue careers which require advance knowledge in these areas.

Major elements in the educational process are curriculum content, classroom teaching, and student learning. Today's educational paradigm places greatest emphasis on curriculum content and classroom teaching. The new paradigm which we must address focuses on student learning. This new paradigm for student learning of mathematics, science, and technology should be based on integrated learning standards.

MST LEARNING STANDARDS

If this new paradigm for mathematics, science, and technology learning is to become a reality, fundamental systemic changes must be made in our educational institutions. These systemic changes require major shifts in the way teachers, administrators, parents and the public at large think about and support education. A major change in beliefs and ways in doing things is required. The implementation of change will require that teachers and administrators work together as a team to develop new mind sets as well as the curricula to support these directions. This will require more inservice learning of existing staffs in both process and content areas. The change will require fundamental changes in teacher education at the university level as well. These activities will also, undoubtedly, require additional financial support as well as the personal commitment of time.

The committee had as its objective the identification and description of *skills, knowledge and values* in mathematics, science, and technology needed by all citizens to sustain and enhance themselves and their nation in a increasingly complex technological society. These are grouped in what are called learning standards. The learning standards for mathematics, science, and technology are viewed as a basic part of the students' intellectual and skill capabilities when they graduate from high school in New York State in much the same way that language skills have been viewed over the years. These skills, knowledge and values will equip students either to enter the working world directly or go on to post high school education. The learning standards are broad process capabilities as opposed to specific factual knowledge. Certain factual knowledge will be included in the standards, but it is important to understand that having achieved a certain standard also leaves the child with a competency to use and build upon. A competency must be exercised throughout life to be kept viable. Active participation in family, community, jobs and further education will all contribute to keeping these competencies growing and vital.

Nine major learning standards for achieving MST literacy have been developed and are currently being reviewed and refined. The fall 1994 version of the learning standards is as follows:

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

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

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

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

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

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

Standard 7: Connecting Themes
Students will understand the relationships among mathematics, science, and technology, identify common themes connecting them, and apply these themes to other areas of learning and performance.

Standard 8: Interdisciplinary Problem Solving
Students will apply the knowledge and thinking skills of mathematics, science, and technology to address real-life problems and make informed decisions.

Standard 9: Preparation for the Future
Students will develop habits of mind and social and career-related skills in mathematics, science and technology education classes that will enable them to work productively with others, achieve success in a postsecondary school setting, enter the workplace prepared to achieve success in different jobs, and possess skills necessary for lifelong learning and continuing advancement.

DESIGN CRITERIA FOR POE CURRICULUM

Learning only becomes meaningful and interesting if students perceive connections between what they know and what they are trying to learn. Thus, contextual or situated learning should be the paradigm for instructional design. Students need to learn concepts, strategies, and habits of the mind that help them see how the various aspects of an increasingly technological world are connected. [6]

We need new interdisciplinary courses that engage students in relevant problems and the study of technological systems. These courses, besides providing contextual learning and study of unifying concepts that connect seemingly unrelated events, must also provide many opportunities for cooperative learning. We should design learning environments (curriculum and instruction) that develop skills for carrying out the adult roles that high school students will soon have to assume. Being able to be an effective team member is one such skill.

We should also design learning environments that model some of the highly successful techniques that are used by today's business and industry. For example, the *just-in-time manufacturing* approach can be applied to education in what can be called *just-in-time learning*. In this approach to learning, concepts and skills are learned as needed to solve problems or design systems. A second example is the use of the notion of *concurrent engineering* in programs that are designed to achieve outcome-based education. In other words, the various aspects of a contextual learning system must be integrated so that we can design more optimum learning environments. For example, in studying the evolution of conventional TV systems to a *HDTV (High Definition Television)* system, students need to integrate the study of human factors, governmental regulatory agencies, the science of pulse code modulation and the mathematics of digital systems as well as the ideas of consumer acceptance and international competitiveness. (See Section VI.)

Business and industry, besides providing metaphors for curriculum design and development, can also be collaborators in the design and development of instructional systems and curriculum that are based on the design criteria that are discussed above, namely:

Contextual Learning,
Connections via Unifying Concepts,
Cooperative Learning, and
Concurrent and Just-in-Time Learning.

A fifth "C" that can be added to already discussed four "Cs" of education reform is **constructivism.** The constructive approach suggests a design criterion that specifies design features which result in learning activities that provide opportunities for Engagement, Exploration, Explanation, Elaboration and Evaluation. A modern learner-center instructional system can be designed using the five "Cs" of educational reform and the five "Es" of the constructivist approach to learning. The most compelling reason for using these design criteria is that the resulting learning environments will promote lifelong learning.

In the past six years, the author of this paper has been collaborating with a group of colleagues in New York State in the design of a high school course, "Principles of Engineering," which used these design criteria (five Cs and five Es). These design criteria guided the development of the learner-centered "Principles of Engineering" course that is centered around six major conceptual areas. Real-world case studies are used to help students learn how the engineering concepts are applied to the study of real problems and systems.

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TECHNOLOGICAL LITERACY: MST INTEGRATION

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Technological literacy refers to the understanding of modern technology, its capabilities and limitations, underlying concepts, and societal impacts. Technological literacy spans the range from how specific devices or machines work to the understanding of the more complex systems for satisfying human needs and wants. Furthermore, technological literacy includes not only the application of scientific and mathematical principles underlying the devices and systems, but also consideration of the human, environmental, and societal impacts.

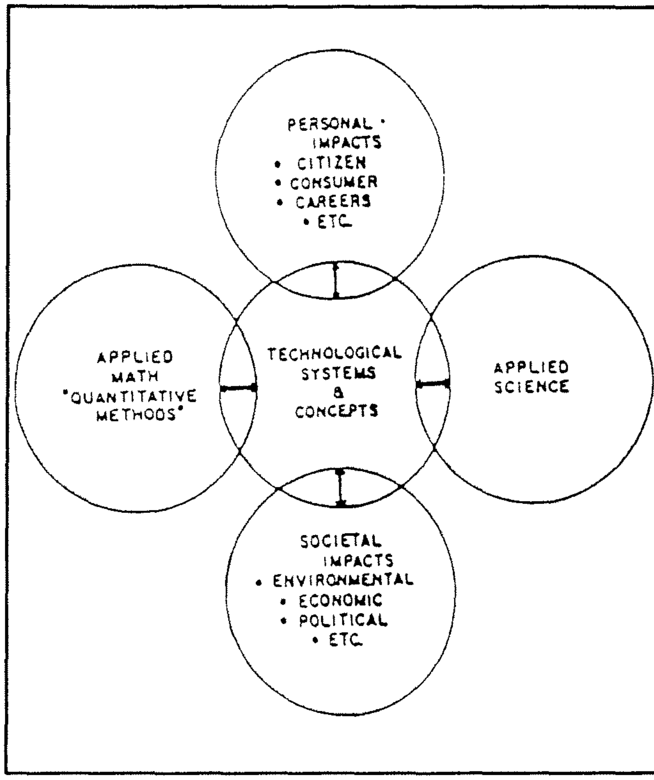
When designing curriculum to help students to achieve technological literacy, categorize the knowledge base into five content areas:

- Technological Systems and Engineering Concepts
- Application of Science Concepts
- Applied Math: Quantitative Methods
- How Individuals Interact with Technology
- How Technological Systems Interact with Other Systems.

ASPECTS OF TECHNOLOGICAL LITERACY

Since technology education includes the study of how technology works and how it interacts with other societal systems, only an interdisciplinary approach to its study is appropriate. In my view, students need to study how five major content areas interact in today's technology-based society.

The connections among the five major aspects are shown in the following figure. Our approach in the Department of Technology and Society is to start with the study of specific technological systems and related concepts. Ideas from the other four domains are introduced as needed. However, the focus of a course can start with any of the other "circles of knowledge."



Interaction of five major aspects of technological literacy

UNDERSTANDING TECHNOLOGICAL SYSTEMS AND CONCEPTS

All technologies have evolved to help people better satisfy human needs and wants. Societies have developed techniques for using tools, materials, energy, information, and human resources for satisfying these needs and wants. A

*Professor Liao cochaired the New York State MST Curriculum and Assessment Committee that guided the development of a new Framework for MST Integration. The other two cochairpersons were F. James Rutherford, Director of Project 2061 of the American Association for the Advancement of Science (AAAS), and Edwin P. Przybylowicz, retired Vice President of Eastman Kodak Corporation systems model can be used to clarify the operation and behavior of technological systems. Technological systems are designed and developed with engineering concepts and apply concepts from other disciplines. Technological systems result from engineering design and development. Engineers use mathematical and scientific concepts in their work. Thus, understanding of the behavior of technological systems requires study of how scientific and mathematical concepts are applied. But other concepts underlying modern technological systems are unique to engineering. For example, the control of systems via feedback is the basic concept of automation. Other concepts relate to ergonomics (human factors engineering) and aspects of decision making (criteria, constraints, modeling, and optimization).

APPLIED MATHEMATICS AND SCIENCE

The application of mathematical and science concepts and techniques to the analysis of socio-technological problems and issues makes the study of abstract concepts more concrete and meaningful. Many educators, such as Morris Shamos, feel that it is the best way to help liberal arts students make sense of these subjects (Shamos, 1983).

From a pedagogical perspective, studying disciplinary concepts, via applications, adds relevance to the learning experience. Students who are often "turned-off" to regular mathematics and science courses find technology-based courses to be more interesting and meaningful (Liao, 1983).

In order to study technology-based problems in a more precised and rational manner, both quantitative and scientific methods of analysis must be used. For example, the study of alternative energy sources requires that students learn how to measure amounts of energy and what happens when energy is converted. Risk analysis requires that students understand probabilistic models and how they are used.

TECHNOLOGY AND THE INDIVIDUAL

As individuals, we interact with technology as human users and citizens of a democratic society. As users of technology, we must learn to choose the most appropriate technology to satisfy our needs in the home as well as in the work environment. As more and more contemporary issues relate to the societal impact of technology, we need to learn how to use relevant information to make more informed decisions. Those of us who create new technology, besides understanding technical concepts, must also be knowledgeable of human and societal impacts.

This aspect of technological literacy, for most of us, primarily deals with learning the concepts and techniques for making the most cost-effective use of the technology. Decisions about selection, use and maintenance of consumer products require an understanding of both the basic information about the product and the process of decision-making.

Technology must be designed with the human user in mind. The match between the technology and the human user (Ergonomics, or human factors engineering) is crucial to the optimization of health, safety, and comfort levels.

Besides making decisions about consumer-related technologies, individuals must also participate in local and national decisions about the choice of complex systems for satisfying our needs for shelter, food, energy, and security.

SOCIETAL IMPACT OF TECHNOLOGY

Another aspect of technological literacy is the ability to understand the limitations and capabilities of current and emerging technologies. Some people erroneously believe that technology can solve all our problems; others, equally naive, blame technology for most of our ills. These two extremes can be avoided if people learn what technology can do, what it cannot do, and how to deal with it.

Other aspects of the social science component of technological literacy include understanding the historical role of technology in human development, the relationship between socio-technological decisions and human values, the trade-offs in the use of alternative technological systems, the changes occurring in high technology areas (such as computers and genetic engineering applications), and the role of technology assessment as a method for studying the environmental, social, political, economic and other consequences of developing and using futuristic technologies.

TOWARD NEW TECHNOLOGY EDUCATION STANDARDS

At the kickoff meeting of the National Commission for the "Technology for All Americans" project, held on January 19-22, 1995, everyone agreed that one of the unique features of technology is that it is an *integrative discipline*. Technology studies require an interdisciplinary approach. Recognizing this important aspect of technology studies, the New York State Education Department formed an interdisciplinary committee in 1991 to create a new MST (Math, Science, and Technology) Framework. In March of 1994, a draft of the MST Curriculum and Assessment Framework was published and distributed for comment. Currently, the framework is being revised.

Four of nine standards in the MST Framework explicitly call for MST integration. The first standard recommends integration of the study of mathematical analysis, scientific inquiry and engineering design. One way of achieving this standard is the study of technological systems (how they are designed and how they work). For this approach, relevant math analysis and scientific inquiry are introduced as needed to learn how systems are designed and how they operate. The second and seventh standards focus on unifying concepts that connect the three disciplines. Finally, the eight standard recommends students engagement in interdisciplinary science, technology and society problem solving activities.

OVERVIEW OF CURRICULUM MODELS FOR INTEGRATING MST

Three models for integrating MST concepts and techniques for implementing the models are described below. Specific examples for the three models are also presented. The three models provide concrete approaches for addressing standards one, two, seven, and eight of the New York State MST Curriculum and Assessment Framework.

One model for integrating MST is the study of technological systems (how they are designed and operate). Relevant math and science topics are introduced as needed to analyze design and explain the function and operation of the technological system. For example, the study of the current transition from current NTSC TV standards to a future HDTV standard requires MST integration and broader integration of knowledge about public policy decisions by government agencies, such as the FCC. The science of human vision and the mathematics needed to determine quantitative standards for TV pictures provide concrete examples of MST integration. (MST Framework: Standard 1)

A second approach to integrating MST is via the study of unifying concepts or the big ideas that link these three ways of knowing. Concepts, such as systems analysis, modeling, optimization and patterns of change help students to consolidate knowledge. For example, MST subjects all provide tools for helping students understand the behavior and uses of periodic patterns, such as sound waves and electromagnetic waves. (MST Framework: Standards 2 and 7)

The third approach is the study of contemporary Science, Technology and Society (STS) issues and problems. Students need to be engaged in using MST concepts and techniques to study the significance of the problems and potential solutions. Study of STS problems, such as solid waste management or auto safety require application of MST knowledge to the process of technology assessment which include economic and risk assessments, environmental impact analysis and study of public policy alternatives. (MST Framework: Standard 8)

Using mathematics, science, and engineering concepts as tools to design and analyze the operation of technological systems is a motivational and effective method of MST integration. Students can also better connect MST studies if they are helped to learn the unifying concepts for linking the MST disciplines. Finally, the application of MST knowledge to the study and search for solutions to STS problems provides more meaningful education.

TEACHING ENGINEERING DESIGN

E.F. Thacher

CHARACTERISTICS OF DESIGN

DEFINITION

Engineering design is the choice-making process used to evolve a set of instructions for making an artifact or developing a system to meet a need. It begins with broad concepts and continues in the direction of ever-increasing detail. The process is iterate because some early decisions must be made with incomplete knowledge.

EXAMPLE

Suppose a man hires an architect to design a house. The man has purchased a lot of a certain size, which has a view to the east and is located in a certain climate region. He wants the house to have low heating costs. His children are no longer living at home. He and his wife have avocations they want to pursue at home. They are fond of light and color and interestingly-shaped rooms. And, they have an idea of how much money they can spend on the house.

The architect must transform this small collection of artistic feelings, facts, and requirements into a set of construction plans for a house. The need is poorly defined relative to the construction plans. What does "low heating costs" mean in terms of insulation in the walls? How is a liking for light, color, and interestingly-shaped rooms to be realized by the size and orientation of the windows and the room layout? Where and how should the house be placed on the lot? How do the features of the house relate to its cost? The number of house configurations that could answer these questions is very large; each of them is a possible "right answer." But, there is no unique right answer.

The architect decides to enhance the view to the east by placing a large window in the east wall of the house. But large windows, even modern two-pane designs, are also large heat leaks. So, the requirement to enhance the view conflicts with the requirement for low heating costs. It may even conflict with the budget; large windows are expensive. The customer's problem statement is not self-consistent because the requirements conflict.

The architect and the customer meet to clarify the problem statement and to discuss solutions. The architect shows the customer some preliminary sketches. Viewing these proposed solutions begins to clarify for the customer what he means by, say, interestingly-shaped rooms. This room here is not interesting, but that one is very interesting, even exciting. The architect's insight into the customer's desires is also improved. Suggesting solutions is a way of understanding the design problem.

The solution requires the architect to apply knowledge drawn from several fields. For example, he must understand how to control the climate in the building, how to provide a proper structure, how to control the project's cost, what laws and standards must be followed—besides how to shape the building and arrange its interior space to please the customer. Design requires the synthesis of knowledge from diverse fields.

The architect may make some preliminary drawings and suggest to the customer that they be given to builders interested in bidding for the construction of the house. The architect wants to collect suggestions from the builders for making the house more buildable. Design cannot be separated from manufacturing; the way something is to be built influences how it is designed, and vice versa.

The solution to the problem is a set of instructions for building the house—the construction drawings. This is a communication packed with information for the builder. Along the way, the architect has communicated orally, and probably also in writing, with his customer. The customer, the architect, and the builder have collaborated. They must communicate in order to collaborate; communication is essential to design.

The design problem confronting the architect has characterists that make it difficult to solve. The problem is poorly defined compared to the information necessary to solve it (the construction drawings). It contains requirements that conflict with each other. The architect's, the customer's, and the builder's understanding of the problem depends upon the solutions which are proposed and the way the building is to be manufactured. There is a range of possible solutions, but no unique solution.

Any problem having the characteristics given in the preceding paragraph is called "ill-defined" or"ill-posed." As the example suggests, these terms describe the essential nature of design problems.

SOLUTION PROCESS

Ill-posed problems are the norm in architectural design, as they are in engineering design and other creative activities. For example, the writing process and the engineering design process are identical. The characteristics of ill-defined problems, whether they are manifested by a writing "design" task or an engineering design task, are the same. Therefore, the process used to "solve" them is the same. The engineer first clarifies the problem statement, then creates and chooses between alternate solution concepts, synthesizes diverse areas of knowledge, moves recursively between stages in the solution as revision requires, and finally, produces a document that clearly expresses the idea. But, this also describes the writing process.

More discussion of the solution process and another example of its application may be found in an article on "Engineering Design" by Hardin in Department (1992).

TEACHING DESIGN

What are the desired outcomes of teaching design? There are three: acquire skill in solving ill-posed problems, in engineering communication, and in collaboration. Skill in solving ill-posed problems is the most important.

Contrasting Problems

In standard technical courses students are accustomed to well-posed problems drawn from a single field of study: a train must leave the station at noon and arrive at a town 200 km away by 4 p.m., at what average speed must it travel? This is a problem in physics only; all the information needed to solve this problem is known, the solution is unique: 50 km/h. This type of problem is rather tidy, not messy and uncertain like a design problem.

Thus, when students are given a design problem to solve for the first time, the lack of definition is disconcerting to them. What should be done first? Where are the formulas? What specific result is required? The teacher may hear complaints ("But, what do you want us to *do*?) or even sense resentment. It is as if an implied contract between the students and the educational process has been violated. Hasn't their task always been: study analytical techniques, do homework consisting of well-posed problems, and then take well-posed tests on them? Now, the student has to do more; she has to invent the problem, a task the teacher or the textbook always did, and there is no single, safe, sure answer. The design problem may even force some learning beyond what has been required in technical courses which the student has taken; the student must do research. This, some students may regard as particularly unfair. Or, it may force them to search out and apply knowledge from nontechnical areas, such as economics (very common), or even ethics. They may regard this study as not "design," and therefore, irrelevant.

On the other hand, students who do not do particularly well in traditional lecture-homework-test courses may shine in design projects. These students may have prior experience in solving design problems. They may have modified cars, done woodworking, made clothes, and so on. They have, therefore, acquired some confidence in attacking ill-posed problems. Or, if they have a hobby, such as amateur radio or rock collecting, that requires extra study beyond the normal school requirements, they may be accustomed to learning on their own through research. Tests are an unavoidably narrow sample of a student's knowledge and force its application under time pressure. Time pressure causes fear; fear causes errors. Also, tests do not usually exercise the student's creativity. So, tests do not usually allow students to demonstrate their "design" talents. These qualities are brought out by design projects, which have a real-world flavor that can motivate self-study. They require creativity. And, being able to work under time pressure is not always an important factor in success.

Approach

Well-posed problems have been fed to the student like mother's milk. The goal of education is independency, not dependency. However, it is probably best to stop the mother's milk gradually, as the child matures, not immediately after birth. Similarly, all the aspects of the design problem should not be introduced at once; this can be overwhelming. The students must be weaned.

Focus first on solving ill-posed problems individually, without forcing the students to cope with the additional complications of communication and collaboration that come with working in a design team. These should be added later. Begin the weaning process by assigning ill-posed problems, but feed them to the students by interacting with them individually as they work through the solution process.

Break the problems into digestible parts that fit into the structure of the design process and have the students share their results piecemeal. Meanwhile, the instructor can solve a problem at the same time and share the results to show the students how to proceed. The ideal maximum student-instructor ratio for this type of instruction is roughly 15 or 20 to 1. The class should not also be formally studying some related theory with its homework and tests. Full attention, and more time, can then be devoted to learning design.

This does not mean that theory they have learned, or even are learning in other case studies and courses, will not play a role. The design problems should be configured to make use of what they know, so they have a place to begin. (Design teaches them the answer to their frequent question, "Why did we study that?") Ideally, pursuit of the solution will lead them to learn beyond what they know, especially if the problems relate to something interesting to them. The problems must not have unique solutions, but need not possess all of the other ill-posed characteristics. The main idea is to learn the solution process. Such stripped-down, introductory design problems will be called "open-ended" problems, after their principal characteristic.

Here are three examples of open-ended problems. They are based on, or inspired by, chapter-end problems in Giancoli (198O), a high school physics text. Each is followed by a brief summary of the background information required keyed to chapters in Giancoli, and some hints to start the student's research.

Problem One: Soil at, say, four meters below the surface stays at an approximately constant temperature year round. The temperature of the air fluctuates below and above this subsurface temperature. Investigate the feasibility of using a heat engine to produce electric power from the fluctuating difference between the air and subsurface soil temperatures (call this "soil-air thermal energy conversion," or SATEC). What would the maximum possible efficiency of the engine be? Include a schematic of your engine concept. Describe any special characteristics the engine should have, such as its "connections" to the air and the soil.

Summary One: The background information for this problem is the material on heat transfer in Chapter 9, and the first and second laws of thermodynamics in Chapter 10. The idea of exploiting soil temperature differences is similar to that of exploiting the temperature difference between the surface and subsurface ocean water, or ocean thermal energy conversion (OTEC). An experimental OTEC plant has been built near Hawaii. Air temperature information can be obtained from the National Weather Service, from local airport weather records, or from reference books in the library. The National Renewable Energy Laboratory (or NREL, formerly the Solar Energy Research Institute) in Golden, Colorado, publishes a book giving monthly average temperatures for a large number of locations in the United States. The soil temperature below the frost line can be estimated from the water temperature in the city mains or from well water temperatures.

Problem Two: The local fire department is trying to establish a relationship between the height of the ladder the fireman stands on and the flow in the firehose for various pumping pressures because they are trying to build a case for buying a new pumper. They are also interested in how high on a building the stream from the hose can reach for a given ladder height and hose pressure. You have been hired as a consultant to find out these things for them.

Summary Two: The background information for this problem is the material on Bernoulli's equation in Chapter 6. Information about firehoses and ladders can be found by talking to the local fire department. Atmospheric pressure records are sometimes kept at nearby airports if a weather station or Federal Aviation Agency flight service station is located there. However, if no records are available, the variation in atmospheric pressure from the standard value of about 101 kPa will have a small affect on the flow from the hose. The student should be guided into at least a qualitative estimate of the error in his calculations. For example, what affect will aerodynamic drag on the water stream have on the estimate of the height the stream can reach?

Problem Three: A ballistic pendulum is a device for measuring the speed of a bullet. The bullet is fired into the pendulum bob which then holds it but swings up a distance that depends on the velocity of the bullet. A marksman who likes to load and test his own ammunition, hires you to design a ballistic pendulum for him to measure the muzzle velocity of his 0.22-calibre loads.

Summary Three: The background information for this problem is the material in Chapter 5, on conservation of energy and momentum. The student should be asked to show from this information (with some simplifying assumptions) that the relationship between the bullet's velocity (v) and mass (m) and the pendulum bob's mass (N) and height of swing (h) is

$$V = (2gh)^{1/2} (m + N)/m$$

Again, the student should be required to give at least a qualitative discussion of the errors introduced by neglected effects. For example, what effect will energy dissipated in the deformation of the pendulum bob have on the calculated velocity?

The emphasis in these problems is on making an approximate model of a system in order to understand the main features of the system's interaction with its surroundings. Engineers design by making such models. Through the models they learn how to configure the system to make favorable changes in the interactions. For example, by modeling the rolling resistance of a car, engineers learn how to reduce that resistance and thus improve fuel consumption. As Liao points out in his article "Modeling" in Department (1992), modeling allows forecasting. Thus, an accurate model reduces trial and error—build and test, which is expensive and time-consuming—to a minimum.

On the other hand, what is neglected in a model introduces error. Aerodynamic drag on the pendulum bob of Problem 3 was neglected. Drag will shorten the rise of the pendulum, causing the measured velocity to be less than the actual velocity. How could this error, or at least bounds for it, be estimated? If the error is too large, can the design be modified to reduce it, say by streamlining the bob? Or, is it simpler to include the drag in the model?

The model embodies the engineer's physical understanding of the device under study. Nothing will probe and strengthen this understanding more deeply than having to answer questions about errors. Reports, written and oral, should include discussions of such issues. However, students are not accustomed to thinking of calculations as fallible. The instructor will find it necessary to work with the students to help them develop error-analysis ability.

Students think that they have no experience in modeling. As implied elsewhere, this stems from how technical courses are traditionally taught—not a explorations, but as formulas to be learned. However, probably the students have had unrecognized experience in explorations from other courses.

Suppose in a literature course students are required to write an analysis of some characters in a play. They must derive possible relationships between the characters based on the clues given in the play by the author. They may have to research the author and her times in order to put the play into a context that will clarify the author's thinking. But this is precisely the modeling process; the modeling process is exploratory thinking.

The structure of the play and the knowledge of the author and her times constitute a set of rules which (the analyst expects) should be obeyed by the characters. These are literary analogs to the laws of physics which must be obeyed by, say, a ballistic pendulum. The relationships derived between the characters are analogs to the relationships derived between mass, velocity, momentum, and energy that describe the operation of the pendulum. The model of the play may provide a correct analysis of the motivations of the characters, and correct insights into the playwright's thinking—or it may not, depending upon the weights given to the elements of the model and what is left out of it. Similar results come from engineering models.

The teacher may be able to reduce the students' uncertainty about modeling by drawing upon this unrecognized experience. The teacher could show the students that this is not really a new process for them, but one with an underlying structure that they have used before.

Some students may have had experience building and operating machines. This experience can help these students with their models. Reality is too complicated to model completely, so judgements must be made about what effects to put in the model. Experience with other machines would perhaps suggest that aerodynamic drag could be left out of the ballistic pendulum model because it will be small since the bob is massive and travels relatively slowly. The instructor's experience and insight can be used to guide students with no experience.

Hands-On Experience
Design-and-build projects should be included in the course. The device to be designed and built should perform only a simple function, such as hoisting a weight or turning a corner. The built devices can be evaluated by staging a contest, with points awarded for the quality of the device's performance. Students should also be required to submit a report on their design. The report should contain the expected performance of their device and instructions on how to build it. (Of course the reports also provide a portion of the grade. This is doubly important because disaster sometimes strikes during a competition.) Rules should be established so that the devices are built from cheap, easily obtained materials. West (1989) reports a project of this type for which the students were each given a kit of parts donated by companies.

Such assignments help students learn how to design devices that can be built. They provide fabrication experience, something that many students do not have. They give experience in testing. This latter experience is very valuable The students observe the performance of a device designed according to a certain model. If the device's performance does not meet the predictions of the model (and this is the norm), the students must find out why in order to improve their design. Their practice at error analysis will now come in to play. They may have already anticipated the errors that their performance testing discloses. But if unanticipated errors appear, they have been armed with the confidence to explore and understand them.

Learning to solve design problems always involves the discovery of knowledge new to the student. This is one of the advantages of studying such problems; they are always explorations. Among the design projects reported by Pittel (1992) was a suspension bridge built of garden hose and PVC pipe by junior high school students. The project was supervised by Mario Salvadori, a retired professor of civil engineering. "Kids learn because we try not to give them the answer" he says. "We lead them to discover it."

Classes
Meetings of the class need not be frequent. The instructor can help individual students, or groups of students at convenient times and places set aside by the course plan. Class time can be devoted to relaxed, interactive sharing of their ideas and problems by the students with each other and the teacher. The idea here is to learn from each other in an atmosphere which emphasizes learning rather than attainting grades, a more professional atmosphere. In this kind of class, the instructor becomes more of a guide and resource and less of an authority figure. In fact, this aspect of teaching design can be challenging for a teacher accustomed to teaching by formal lectures, and for students accustomed to these structured lessons. The teacher has to learn a new role of mentor and resource; the student has to take on more responsibility for learning.

The students learn from each other outside of class too, but the teacher should clearly define what constitutes dishonest behavior. One way to do this is to introduce the students to the rule used by professional engineers: if you use another engineer's idea, you give that person credit in your report. This can range from an acknowledgement of helpful discussions to a formal citation in the text referring to a technical article in the bibliography.

Communication

Communication on a design team requires effort; it is not the casual conversation on familiar subjects or the quick exchange of greetings most students are accustomed to. It means discussing design choices, writing technical specifications, reporting calculations, keeping clear and complete records, making drawings of parts, and writing a design report.

This more intense, focused communication is often difficult for students in design teams to achieve. They are not accustomed to keeping each other informed in detail. Meetings require extra time, usually outside of class, and must be at a mutually agreeable time and place. Meetings to discuss technical issues and to make decisions require everyone on the team to be prepared by the time of the meeting, irrespective of the demands of other courses.

As an aid to communication, an individual, or design group, should always keep a design notebook. This does not have to be in any particular format, but if a design report is to be written it is very helpful to keep the notebook organized along the lines of the report. The notebook should contain notes of group meetings, concept sketches, calculations, prices and catalog information—anything to do with the design. Students in a design group can review the notebook to recall the what and why of a particular choice; the teacher can review it to keep up with the group, or individual.

The design notebook is a kind of journal; it is really a means for the designer to communicate with herself or himself. It is a way of sculpting ideas. The first attempt at writing an idea may seem unsatisfactory, usually after the writer returns to it after an interval. Perhaps then the writer has gained some perspective and additional understanding and sees where the original words are not clear, or where the idea is incomplete.

The synergy between writing and learning to design should be exploited at every opportunity. Practicing one process is equivalent, in essence, to practicing the other. Recognition that they have experience in this process, through writing for other classes, should help to dissolve the anxiety students feel when confronted by an engineering design problem. Writing well, then, becomes for the engineer not just a means of communicating clearly, but a means of developing a deeper grasp of the quintessential activity of the profession: design.

The end product of the design process is a set of instructions for making the design. This communication must be clear and in adequate detail. Just how much detail is required, even for seemingly simple devices, is sometimes a surprise to students. Requiring students to build each other's designs would shed light on how well the designs have been described. The builders could keep a record of each fabrication step; was it clear from the drawings, or did they have to ask the parent designers what to do?

Collaboration

Cast points out in his article on cooperative learning in Department (1992) that student-engineers should acquire experience in collaboration. Also a large project, or a large class, often dictates forming teams. Collaboration implies organization—dividing up the task so that the work is evenly distributed and so that the pieces of the design problem can be solved more or less in parallel. A way to drill the teams in collaboration is to give assignments that require it. For example, each member of a team could be required to contribute to an oral progress report, say by discussing one aspect of the project using a transparency and an overhead projector.

A large team, one with four or more members, needs a leader, someone who will accept responsibility for coordination and serve as a contact for the teacher. Unless experienced in leadership, as a leader on an athletic team or in some other organization, students are sometimes reluctant to take charge of other students. The instructor should interview teams informally from time-to-the to try to assess how well they are being led.

Students are accustomed to working at their own pace and have widely varying levels of knowledge and maturity. As a result, the work load is frequently not uniformly distributed over the team. The student-leader has only moral persuasion available to force cooperation without turning to the teacher. So an unequal workload may lead to complaints, and the instructor may have to interview team members in order to apply pressure to adjust the balance.

Allowing the students in a design group to grade each other on teamwork can also help. Each group member assigns a fractional grade between zero and one to the other members. A grade of one means that the student being evaluated did her or his proportionate share of the work—1/3 of it in a three-person team, 1/5 in a five-person team and so on. A grade of zero means no participation. The instructor averages the teamwork grades for each member and multiplies the team's project grade times the average teamwork grade. This product becomes the project grade for each individual.

Skills in Computer programming, CAD, word processing, and fabrication may be non-uniformly distributed over the class. So when forming design teams it is prudent to make sure that each group includes at least one person skilled in one of these areas.

Tools

The bibliographies of the case studies in Department (1992) should be consulted for helpful materials and methods. For example, the "Structures Case Study" by Rock gives several references by and about Mario Salvadori (mentioned above).

Texts for teaching design abound. Cross (1989) is a handy-sized text for an introductory course and would be satisfactory in a high school class. Walton (1991) is an example of a more advanced text. The advantage of a text is that it contains instructions for the design process: how to write specifications, techniques for stimulating the creation of design concepts, techniques for evaluating and selecting concepts, case studies, methods of making engineering drawings, etc. The disadvantage of a text is that it may tempt the instructor to approach teaching design by lecturing and giving tests, which is relatively easy, rather than by experience, which requires more time and energy. Design cannot be effectively taught by lecturing. The best use of a design text is as a part of the reference material available to support the actual doing of the design.

The reference material should also include manufacturer's catalogs, compilations of data (the NREL weather data mentioned above, for example), physics texts, and other documents that the students may need. Placing this material into a "design library" in one location will save the students' time.

Computers should be available and equipped with the BASIC language, at least, a word processor, and a printer. Programs for making graphs would also be useful, if they are user-friendly. Computer-aided design (CAD) programs are also helpful, but not essential. Making pictures of objects on a computer screen is not design, but as the acronym states, is an aid to design. CAD programs have to be learned, but not while also learning the design process. Clear, freehand sketches on cross-hatched paper are quite satisfactory, and can be produced more quickly and more easily by inexperienced people than CAD drawings. (Freehand drawings are acceptable in some machine shops, according to Cross.) A CAD program should be available for use by students who have experience with CAD.

OTHER ISSUES

What other issues might be included in teaching design? There are many: safety, statistical quality control, economics, ergonomics, and even ethics, to name but five. These are important issues. Product statistical quality control bears directly on the issue of product quality, and needs to be understood and practiced by engineers. Economics, as has been mentioned, often strongly influences design choices. Choices made during the design process may have strong ethical implications, especially those relating to product safety The instructor may find, however, that it will be difficult to formally cover all of the issues which cluster about the design process in a single, introductory course, and still to thoroughly teach the design process. It is more effective to focus on realistic design problems; these other issues will sometimes emerge naturally from the context of the problem, particularly safety, ergonomics and economics.

Design education is under scrutiny at all levels, especially at the college level. Dixon (1991) is a sample of this scrutiny. This article provides a view of what the goals of college-level engineering education should be. Committee (1991) is a similar study. Both documents make specific recommendations. Pittel (1992) tells of design programs at the secondary school level, and even before it. Familiarization with such thinking and programs will help the instructor find a context for an introductory high school course.

The function of introductory instruction in design should be to entrench the knowledge of how to solve ill-posed problems. This is the foundation upon which later work will stand, the first step in a process of learning design—a process that will extend beyond the student's period of formal education. But this foundation will do more, for all real-life problems are "design" problems. That is, they are ill-posed. Skill in solving design problems is therefore applicable to solving any real problem. If the goal of education is truly independency, to free and help unfold the individuality and potential of each child, to allow them to see and recognize themselves—and not to just impose our own opinions about them, then the design approach should be the paradigm for every course.

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APPENDIX D
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