Chapter 2

Getting Ready

Making It Work

The engineering framework for problem solving challenges students to take responsibility for their own learning. It also demands a strong commitment on the part of the teacher.

The teacher's primary tasks are to help students pose questions they can successfully pursue and to interpret the results of the students' work in terms of the appropriate discipline. Full implementation of the engineering problem-solving cycle, though, is more than helping students pose questions and discover solutions. The teacher is called on to develop resources—human resources, paper resources, technical resources—not readily available in standard textbooks. The teacher becomes a mediator of a process that may take students outside the teacher's own area of expertise. When the time comes for assessment, the teacher must oversee a review process that demands much more energy than is required for scoring short-answer quizzes or multiple-choice tests.

Bridging the Gap

Physics teacher Jeffrey Lange poses the question, "How can schools bridge the gap from theoretical on-paper work to the full process—patent research, building a physical model, review panel—especially for other than Advanced Placement or highly motivated students?"

Every school has its own constraints—the flexibility of the curriculum, the structure of the school day, the technology available—and every teacher has ideas for potential implementations. The best scenario is an interdisciplinary team approach with strong support from the administration and the local community. A teacher who feels isolated in the classroom needs to build alliances by offering peer training, inviting colleagues to sit on a review panel, and initiating joint projects with colleagues. Teachers with access to the Internet may use e-mail to communicate with like-minded reformers; those without e-mail can work through professional organizations.

Even in the most supportive environment, implementing change is a long-term process. Some teachers begin by introducing project work above and beyond the ordinary expectations for their course. Others augment their curriculum by adding some, but not all, aspects of the engineering approach to problem solving. Still others integrate problem-solving methods into their current curriculum by displacing traditional course content. Teachers need to assess their particular situations and find the best match. The integrative method works best for most students and teachers, but any implementation places a teacher at the frontier of reform in science and mathematics education.

Supplementing the Curriculum

Some teachers report that even in a course rigidly content-driven, opportunities arise to use the problem-solving cycle. When physics teacher Tony Komon began implementing engineering problem solving in his classes, he remained obligated to provide the content to prepare his students for the New York State Regents Examination. Reasoning that in the typical forty-minute period, the first ten minutes are generally used to take attendance and for other management tasks, he turned those minutes instead into project work: ten minutes a day of formal attention to the problem-solving cycle—the rest of the project work comes out of student energy and a teacher willing to be available to his teams during lunch and after-school hours.[1]

Problem Solving in the Lab

Teachers can incorporate engineering design into laboratory work. When biology Gene Hampton brings students into his lab, he gives them a traditional experiment, for example:

> When yeast is fed different amounts of food, what is the effect on its gas production?

Then he challenges them to design an experiment. The students work in groups to redefine the problem and establish parameters for the experiment. What could have been a simple cookbook exercise becomes instead a unique venture into research design, a mini-project that extends over several lab periods.

Lisa Torres has her chemistry students design their own experiments, and expects them to define both dependent and independent variables. For example, with the class working on gasses, she may set experiment parameters as:

> What is the effect of A on B?

To redefine the problem, each team must decide which gas will be the subject of its experiment and which variables to manipulate. Once two teams have signed up for, say, the effect of volume on temperature in air, that topic is closed.[2]

Torres creates an environment which pushes students to design their own equipment. She purposely keeps only two pressure gauges on hand; if both are in use when a team needs to measure the air pressure of a deflating balloon, the team is encouraged to invent a gauge that will give them the data they need.

Independent Projects

Teachers who encourage students to enter national competitions, such as the Duracell Contest or the Seiko Youth Challenge, find that many of these are open only to individual projects. Teachers, especially those working with students whose social skills are limited, sometimes encourage independent work: “Certain students,” says Gene Hampton, “especially the introverted ones, just work better alone.”

The engineering approach, although it emphasizes teamwork, contains many elements that can be exploited by the single student. Even brainstorming, clearly a group activity, can be simulated when an individual discusses ideas with other students, friends, relatives, or mentors. Other elements of engineering problem solving—constraints, matrix work, iterating—provide valuable structures for an individual project.

1. See “Project Work on Ten Minutes a Day,” p. 88.
2. See “Designing Chemistry Labs,” p. 107.

Integrative Problem Solving

Teachers who choose to integrate engineering problem solving into their courses face the question, "Can I do project work and still teach all the course content?" The answer to this question is probably, "No, not without sacrificing my sanity!"

Taking the integrative approach means being committed to the vision of scientific literacy defined by AAAS' Project 2061. To assert that memorizing the symbols of the elements is less important than being able to ask intelligent questions and find reasonable answers about those elements may mean going out on a limb, but that is a risk teachers may be increasingly willing to take as reformers redefine the terms of twenty-first century mathematics and science education.

Just what content might be jettisoned to make room for engineering problem solving, teachers and administrators will need to decide for themselves. When physics teachers Tom Woosnam and Jim Housley discussed this issue, they concluded that every student of physics must study mechanics; beyond that topic, they suggest, physics teachers can generally define the course of study.

Woosnam presents the problem-solving cycle on the first day of class; so far as his students know, physics *is* problem solving. For his honors physics course, the first semester involves problem solving around the topics of light and optics followed by a thorough grounding in mechanics. In the second semester, students solve problems in relativity, particles and interactions, and electricity and magnetism. Gone are solids and fluids, fluids in motion, and thermodynamics, not because these areas are less important, but because this is Woosnam's choice. Students who need to learn areas of excluded content in order to take the Advanced Placement Physics examination work with him before school and during activity times.

Interdisciplinary Problem Solving

Mathematics teacher Nancy Borchers has drawn a number of her colleagues into project work by initiating interdisciplinary teamwork. Students from the art department worked with her geometry students, as have students from American history, computer science, physics, and Spanish classes. She has also involved several elementary schools in her district by having her pre-algebra students design math games and then teach them to both third graders and their teachers.[3]

Carla Huffman and Laura Rabe team-teach several integrated mathematics-science projects each year. In 1996, their cellular biology and pre-calculus students probed the question:

> Which type of bacteria is best for a spectrum of research?

Environmental science and algebra students took on acid rain; chemistry and advanced algebra students investigated gas laws.

A number of teachers have called on their school technology teachers for expertise and supervision of prototype construction. In Hanover, New Hampshire, for example, science coordinator Carl Mehrbach team-teaches his course with technology instructor David Johnson.[4]

Other teachers have introduced the approach to teachers outside the mathematics and science departments. New York Wayne Snyder reports that colleagues in the Social Studies department have adapted engineering problem solving for their Participation in Government course and that the technology teacher is excited about its potential in his classes. "We envision this method becoming a standard format that students will encounter throughout their high school experience."

3. See "Interdisciplinary Geometry," p. 90.
4. See "Engineering Concepts for Advanced Students," p. 96.

An Entire Course of Problem Solving

Having sold their schools on the tremendous potential of engineering problem solving, several teachers have developed semester or year-long electives that integrate science, mathematics, and technology into a single framework. Karen Falkenberg, formerly a mathematics and science teacher, offered a year-long elective called "Engineering Concepts" that took students through short- and long-term projects. Science teacher Carl Mehrbach has created an engineering class for seniors who have already completed the chemistry and physics curriculum or who have completed one course and are enrolled in the other. Both curricula begin with short-term, narrowly defined problems and gradually work with their students toward a substantial final, open-ended project that moves each team through the problem-solving cycle to patent searches to professional review boards.[5]

"Front-Loading" the Course

However teachers choose to implement Thayer-style project work, they know implementation depends on detailed work before the project starts. "Front-loading" the course, as John Collier puts it, means that teachers put in many summertime hours making sure the structure is in place. Course goals, potential problem statements, timelines, review criteria—all need to be carefully thought out before the first day of class. Potential human resources—colleagues, administrators, guidance counselors, librarians, mentors, review board members—must be contacted and given information on the teacher's expectations. Preparation is indispensible for all teaching, but getting ready for engineering project work requires more than lesson planning. The teacher is the hub of a large network, and managing the network calls for skills above and beyond in-depth knowledge of subject matter and how to teach it.

The rewards are great. Guiding students into the kind of scientific inquiry that mimics the work of the professional engineer, scientist, or mathematician—this is the stuff of real teaching. Students who define their own problems and take responsibility for their own project direction never ask, "Why are we doing this?" They know why they are working so hard, staying after school or meeting during lunch hours. Teachers often report that students, after project work is over, wonder why they can't learn this way every week.

Reckoning the Cost

Designing a device is paperwork; constructing it requires materials, and materials cost money. How do teachers, with tight school budgets, pay for project work?

Grants are one way, of course, although grant writing is tedious and time-consuming. Reform in teaching science and mathematics is high on the priority list of many funders, so a proposal can be worth the effort. Even when grant money is available, teachers still are wise to limit the amount any team may spend for a single project.

Scavenging is another route. Companies are often happy to donate equipment to students who approach them with a clear explanation of their project and their needs. Louise Bennicoff notes that her students, most from low-income families, managed to scavenge a discarded radar system from the California Department of Transportation and an ultrasonic range finder from a local agriculture business. "I just blindly gave assignments," she says, "and the kids found creative ways to get what they needed." For a final exam, she asked students to build a race car propelled by the energy of a falling brick; one car rolled along its appointed course on wheels borrowed from the superintendent's barbeque grill! In more affluent communities, teachers sometimes assume that their students' parents will help purchase necessary materials or equipment, yet "I do stress that the project is not to cost a lot of money," says physics teacher Tom Woosnam.

5. See "A Whole Year of Inventions," p. 94.

Course Goals

Traditionally, the goal of a course is the mastery of a specific body of knowledge considered central to that discipline. Although the AAAS calls for reversing the "accretion of memorized material," teachers are caught in the disparity between the goals of Project 2061 and their classrooms today. Yet, even in content-driven courses, teachers can redefine their goals so that engaging students in active learning is primary.

General Goals

Professor John Collier tells students on their first day of class that his course will

- be interesting, even exciting
- build confidence
- show problems as opportunities
- allow the use of creative energy
- show why engineering is exciting
- permit them to create something novel, do something never done before

As if inviting his students to intrigue, Collier announces that there will be no quizzes, no exams, no homework. Nevertheless, he promises that they will work very hard indeed and will have opportunities to present their ideas for evaluation before a professional review board.

Mathematics teacher Mary Lou Derwent wants her students to:

- explore divergent as well as convergent thinking through brainstorming
- be exposed to the interaction between the agendas of technology and society where there are mutual restraints and tradeoffs
- acquire both a thought process and a tool that is a life-skill

In peer-training workshops, Derwent emphasizes that the goals of project work are to increase students' interest, encourage development of multiple solutions, encourage creativity, expand interdisciplinary work, expand learning into unexplored areas, and foster the students' personal expertise. Project work reduces the teacher's power. "The teacher," Derwent tells her colleagues, "is the coach with the students only dependent on the teacher's knowledge to move them along."

Lynn Stallings, from the University of Georgia, sees a number of critical factors for a course framed by engineering problem solving:

- relevance
- work on project/problem of broad scope
- production of a final product that is valued by those inside and outside the school
- "real-world" working conditions, such as autonomy, teamwork, resourcefulness
- integration of a variety of student skills from different disciplines, such as mathematics, physics, engineering, writing

Integrating Project Goals with Content Goals

Adding these goals to a course already crammed with specific content goals asks a lot of both teachers and students. Teachers who guide engineering electives acknowledge that they have the advantage of not having to worry about whether the course prepares students for a more advanced level of science or mathematics. When the problems are open-ended, they know, not everyone is guaranteed to "learn" the same concepts. For required courses that feed into other courses, the challenge is clearly greater.

As teachers revamp courses, they may want to involve their students in the process, as John Van Ackerman did in when he challenged his physics students to solve the problem of how best to learn physics.[6]

Setting goals, whether with students in a single class or by involving the entire faculty and administration, calls for an assessment of the immediate situation. No one expects the goals of Project 2061 or the standards of the professional science and mathematics organizations to be realized overnight. Teachers do well to set themselves both long-range goals (wish lists for restructuring) and short-term goals (what can be accomplished now).

6. See "Designing a Multilayered Physics Course," p. 105.

Support Networks

The most successful project work is a collaboration with other adults involved as mentors to students and as support for teachers.

Mentors for Students

Traditionally, students with questions go to the teacher for help. Students who choose their own problems to solve often find themselves exploring areas outside the domain of their teacher's expertise. An outside mentor—a professional scientist, technician, engineer or business person—can provide the technical support they need, acting as a consultant and providing feedback at crucial points in the project. Mentoring by adults outside the classroom offers students first-hand experience of how scientists, for example, function in their jobs. Although business and professional people lead busy lives, many are pleased to be informally involved with student projects.

For a mentoring system to work well, the teacher must locate—before the project begins—people willing and able, with expertise in some aspect of the problem area. Colleagues, administrators, school board members, college professors, public officials, hobbyists, as well as business and professional people from the community all are possible contacts. Interested teachers within the school can also be helpful as mentors. Case managers or resource-room teachers can be enlisted to work with students on Individual Education Programs (IEPs), as editors for written work or checkers for math calculations or simply as intelligent "nonprofessional" readers of reports.

Formal Mentoring Programs

Teachers who have established formal mentoring programs have trained mentors in the engineering approach to problem solving. Some train mentors for local science fair projects, knowing that as the approach spreads, it will benefit everyone involved in guiding young scientists.

Science Pioneers, Inc., a group sponsored by The Greater Kansas City [Missouri] Science and Mathematics Alliance, holds an annual "Meet the Mentor Day" when parents, teachers, and students can meet scientists, technologists, engineers, and master teachers on their mentor roster. Science Pioneers offers high school students the opportunity to be science mentors to elementary and middle school pupils, to help them develop ideas for science projects, to advise them along the way, and to show them how mentoring works. Although Science Pioneers was founded to assist in science fair competitions, it enthusiastically endorses the use of its services for high school classes undertaking project work.

Approaching Mentors

Students often need assistance with telephone manners and writing business letters. For Lisa Torres "it is important to monitor letter writing and sometimes to teach phone skills and rehearse these with students. Some are easily frightened and discouraged by switchboards! Writing a script for phone questions helps kids use the phone appropriately."

Students may also need help formulating e-mail requests for help. Kathleen Conn tells of a student who left a message on the America OnLine LabNet bulletin board asking for "help in choosing a science project." "This highly inappropriate request received a sole very appropriate reply," Conn said, "'Please be more specific.'"

More mature students can be responsible for finding mentors. They may already know people in their field of interest—relatives, family friends, neighbors, former students. Seeking out their own mentors can be part of the learning experience. Jim Housley asked his seniors to locate potential mentors in the science departments of the colleges to which they were applying and to work with them via e-mail. Although he edited their initial letters to make sure the requests were appropriate, the students were responsible for tracking down potential mentors.

Housley's first experience with this approach confirmed his sense that he doesn't need to be an expert for students to benefit. "When I started having kids use e-mail," he says, "I didn't know how to use it myself. When the letters [from potential mentors] came back, I nudged certain students to visit the computer teacher who had a university account with access to the Internet, and to try their hand at it. A few had parents who used e-mail. Kids asked one another for help. So it grows."

Once mentors have volunteered their time and energy to a project, it's important to acknowledge their work with at least a thank-you note. Everyone who helps students of Mark Temons receives a letter of gratitude from him as well as letters from his principal and his superintendent and an official public thank-you from the school board at a board meeting.

Keeping Track of Mentors

With a good support system—student mentors, potential guest speakers, review board members, e-mail support—a filing system is essential, preferably one that can maintain information on each person's availability, usefulness to particular parts of project work, and, perhaps most important, time the person has given to the program. Common sense says that someone who has just put in a hundred hours on a first-semester project may not be interested in signing up for the second semester. Where more than one teacher in a community is overseeing project work, a master file may insure that the best support people don't burn out and that teachers do not wear out their welcome in the community.

Support for the Teacher

Without support, teachers become isolated in their separate classrooms, talking to no one but their students or random colleagues on break in the faculty lounge. Teachers need to develop support systems within their departments, across disciplines, and outside the school. A well-run project requires moral, logistical, and financial support, along with expertise from outside sources. Outside support won't lighten the teaching load, but it will make the work more fun as others are drawn into the excitement of student inventions.

In the ideal environment, several teachers from different disciplines work together, guiding the process with enthusiastic support from their colleagues, the school librarian, school board members, the administration, and support staff. Although the teacher is ultimately responsible for the course, many details of the process—students' use of telephones, budgeting, arranging field trips, hiring substitutes to free other teachers to act as consultants and review board members—are best handled by the school's administration and support staff. The school library or media center is where students will begin their research. School librarians can direct their use of other library facilities, either in the community or at a local college or university. If the media center is connected to the Internet, library staff can show students how to find resources across the country. They may also be available to assist students with written and oral presentations and participate further by acting as consultants and review board members.

Outside the school, teachers can look to the community librarian, parents, business and professional people, instructors from the local college or university who may be willing to speak to a class, provide a field trip, act as consultants, or serve on a review board.

One way a teacher can build a successful support network is to offer workshops and presentations to colleagues in their school districts and at regional or national teachers' conferences. Sharing information about the engineering approach to problem solving will help build an enlarged support system as well as help a teacher solidify concepts and techniques.

Support on the Internet

Many teachers keep in touch on the Internet. Dartmouth has set up an e-mail "reflector," so that graduates of the Engineering Concepts workshop can post queries and share classroom experiences. This exchange of ideas and excitement is invaluable, especially for teachers surrounded by traditional teaching who otherwise lack such support.

"Labnet," a teacher-mediated network for science teachers, is a member-only Keyword group available (for a fee) to subscribers to America OnLine (AOL). Each subject area has a folder to which teachers contribute ideas about teaching methods, opportunities for grants, and information on workshops or long-term projects. Because contributors are encouraged to create their own folders, New York teacher Nancy Moreau, for example, created one for Engineering Concepts in the High School Classroom in which she posts information about the Thayer School summer workshop and re-posts items from the Dartmouth reflector.

A number of other ramps to the information highway are available to teachers. In some states, public universities offer free Internet access to teachers, who are asked to fill out an application and describe how the Internet would enhance their students' learning. In other states, departments of education are working to get Internet accounts for teachers with nodes where teachers can have access via local calls. Larger school districts maintain Internet nodes that supply all interested teachers with free accounts. For teachers new to the information highway, the best bet is to contact the state department of education or the state university's Education Department to find out what is available.