INTRODUCTION

Why Engineering Problem Solving?

Three high school students are explaining their underwater navigational device. "What do you get out of this kind of learning experience?" they are asked.

"Well, take me," responds one. "In my regular physics class, I'm failing right now! I've been building things and doing experiments since I was a kid, but I can't seem to learn from a textbook. If I didn't have this class, I'd think I wasn't any good at science."

Schools are filled with students who think they aren't "any good" in science. As America heads toward the twenty-first century with an urgent need for citizens literate in science, mathematics, and technology, bright students—students who love "doing" science—turn away from traditional courses.

Engineering problem solving can propel those students (along with their peers who excel in traditional courses) into rigorous learning experiences within the context of solving problems of the "real world." Working in teams to develop viable solutions, students learn to value their own thinking and trust their own judgment. They develop an appreciation for how science and mathematics work outside the classroom. They learn how to communicate their ideas to business and professional people as well as to teachers and fellow students. Most important, they become fully engaged as they grapple with the less structured problems they will encounter in their future in classrooms and in employment.

A Different Approach to Learning

Imagine a darkened room, an overhead projector showing a prototype design for a wheelchair braking system. A team of inventors is explaining why the disc brake was their system of choice over fly-wheel, ratchet-action, or lever-wedge systems. Team members take turns explaining the testing procedures used and results of the tests, the potential market for the device, the projected variable and fixed costs of a start-up company, and the profit analysis for manufacturing and selling the device over ten years.

An engineering firm pitching a venture proposal? No, these inventors are high school students, their wheelchair braking system the result of a "Product Design Engineering" course given at The Governor's School for Mathematics and Science in Roanoke, Virginia. The theme for the course was "Improving the Quality of Life for Citizens with Disabilities." Other team inventions include a rain shield for wheelchairs and special nail clippers for arthritics. Each team identified a problem, then designed and constructed a device to solve it. The presentation before the professional review board was the students' final exam.

Now picture a high school classroom in South Bend, Indiana, where a team of precalculus students demonstrates its map of a reorganized city transportation system. The cloverleaf design could be a polar curve traversed in either direction. The students explain their formula—the weighting of normal standard scores of population, economic level, and available jobs to give precedence to areas that most need public transportation.

How about a team of high school physics students in Corcoran, California—sons and daughters of migrant farm workers—explaining to members of the Corcoran City Council how to apply the physics of light to determine the optimum color for a headlight to penetrate the dense fog that blankets the community every winter? Or geometry students from Cincinnati, Ohio, discussing the tessellating design they turned into a cracker and its packaging for the Keebler Baking Company? Or biology students on Long Island, New York, demonstrating a design for a sonar device to prevent the accidental netting of dolphins in tuna fishing?

These student teams and others across the country are approaching problems from an engineering perspective. Each team defines and redefines its problem, sets specifications, brainstorms solutions, and selects a single potential solution to explore. As they work together, they know they will iterate the cycle, perhaps many times, until they have devised a solution—a design or a device—that is unique, timely, and useful in the everyday world.

Engineering Problem Solving and Science/Mathematics Reform

Since the early 1980s, high school teachers of mathematics and science have been working toward reform of traditional curricula. Emphasis has been on problem solving, creative thinking, and connections to the world beyond the classroom. Forward-thinking educators from both fields have looked for new ways to foster problem solving in cooperative learning environments. They want to expose students to interdisciplinary approaches. They talk about having students take responsibility for their own learning. They want them to construct their own understandings of the scientific and mathematical worlds.

Teachers, in effect, are describing an engineering approach to problem solving.

Although science and mathematics teachers are often constrained by state- or district-mandated curricula with required topics and tests, many teachers have managed either to integrate the engineering approach into their courses or to supplement traditional coursework with out-of-class project work.

How do they do it?

There are as many solutions as there are teachers. Some challenge their students with problems that take them far from the classroom; others have their students design experiments or solve narrowly defined, discipline-specific problems. Project timelines are as short as a week, as long as a semester. Some teachers expect their students to accomplish the lion's share of project work after school or during study periods; others devote hours of class time; a few have the luxury of designing an entire course devoted to engineering problem solving.

A Working Method for All Students

If the methods of implementation are varied, so too are the students. Reform movements in both mathematics and science call for literacy in mathematics and science for *all* Americans; any educational thrust that targets only high achievers is of marginal value in education reform.

Fortunately, field evaluations confirm anecdotal evidence that student populations traditionally underrepresented in science and mathematics courses—minority students, female students, low-income students, inner-city students, students whose parents may not have finished high school—reap equal benefits.

Louise Bennicoff initiated her Fogbusters project in Corcoran, California (see "Fog Navigation," page 85) with students whose parents are either farm workers or employees of the California State Prison. The student population is 65% Hispanic, a large number of them classified as migrant. Observers of the Fogbusters project—from external review boards to a professional evaluator from Cornell University—have been consistently impressed with the quality of the work done by these students.

Mike Jabot, a physics teacher in Oneida, New York, gives all his students—Regents, Advanced Placement (AP), and "local level"—the same problem statement. The local-level students often have better backgrounds in building or tinkering and so can act as "mentors" to the others, both in evaluating the feasibility of an idea and during construction of the prototypes. Jabot reports that outside review board members, without knowing which teams are Regents or AP and which are local-level, generally assign scores for the local-level teams equal to and often higher than those for the AP and Regents groups.

The problem-solving cycle also works beyond mathematics, science, and technology. Laurel Macartney, a chemistry teacher from Redmond, Washington, used the framework to help students design their senior projects, a year-long requirement for graduation supervised by the English department. Students who have had trouble selecting a project, who have, in fact, few interests in school and want only to "get by," use the problem-solving cycle to find areas to which they can apply themselves. For some students, engineering problem solving not only helps them hurdle a requirement, it propels them toward college careers they've never considered.

Realities and Visions

Teachers whose ideas are described in this book have applied engineering design concepts to foster all kinds of student projects. While their work fulfills the new mathematics and science standards, it also functions within the curricular constraints of their particular schools. These teachers know that the approach is an idea in motion, that as they adapt the basic methodology to fit their particular situation, their teaching develops to incorporate finer points. The fluidity of engineering problem solving allows them to work in the realities of today while moving toward the visions of tomorrow.