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ENGINEERING THE FUTURE WITH AMERICA'S HIGH SCHOOL STUDENTS

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SUMMARY

The number of students enrolled in engineering is declining while the need for engineers is increasing. One contributing factor is that most high school students have little or no knowledge about what engineering is, or what engineers do.

To teach young students about engineering, engineers need good tools. This paper presents a course of study developed and used by the authors in a junior college course for high school students. Students learned about engineering through independent student projects, in-class problem solving, and use of career information resources.

Selected activities from the course can be adapted to teach students about engineering in other settings. Among the most successful techniques were the student research paper assignment, working out a solution to an engineering problem as a class exercise, and the use of technical materials to illustrate engineering concepts and demonstrate "tools of the trade."

INTRODUCTION

The United States is facing a serious threat to our economic, social, and environmental well-being. Problems include a fiercely competitive global economy, energy shortages, depletion of natural resources, degradation of the environment, and deterioration of infrastructure, all complicated by shrinking federal budgets. Because these problems have substantial technical components, engineers are well qualified to contribute significantly to their solutions. Although some see the present employment market for engineers as weak, we believe that this country's future depends on engineering talent in all disciplines to provide cost effective, innovative, and permanent solutions to these interdisciplinary, national problems.

Future engineers are students attending elementary and high schools today. The number of high school graduates enrolling in undergraduate engineering programs, however, is declining. At the university level nationwide, the number of new college freshmen enrolling in engineering programs declined, with a corresponding decline in the number of Bachelor of Science degrees in engineering awarded, from almost 80,000 in 1986 to 66,000 in 1990.

There are many ways to encourage more young people to choose engineering as a career. *Engineering Careers*, the course described in this paper, was developed as one means to do so. Figure 1 illustrates some complementary ways in which a growing number of programs today, including *Engineering Careers*, are contributing to an overall solution to our national dilemma.

Some of these programs help to *inspire* young people to pursue scientific and technical study by drawing on the very powerful images provided by space exploration. The use of such imagery to inspire students to pursue technical careers is an excellent technique. Inspiration alone, however, is not sufficient. We also need to *inform* students about engineering. Many students face the difficulty of deciding what career to choose without the benefit of some very basic information about engineering.

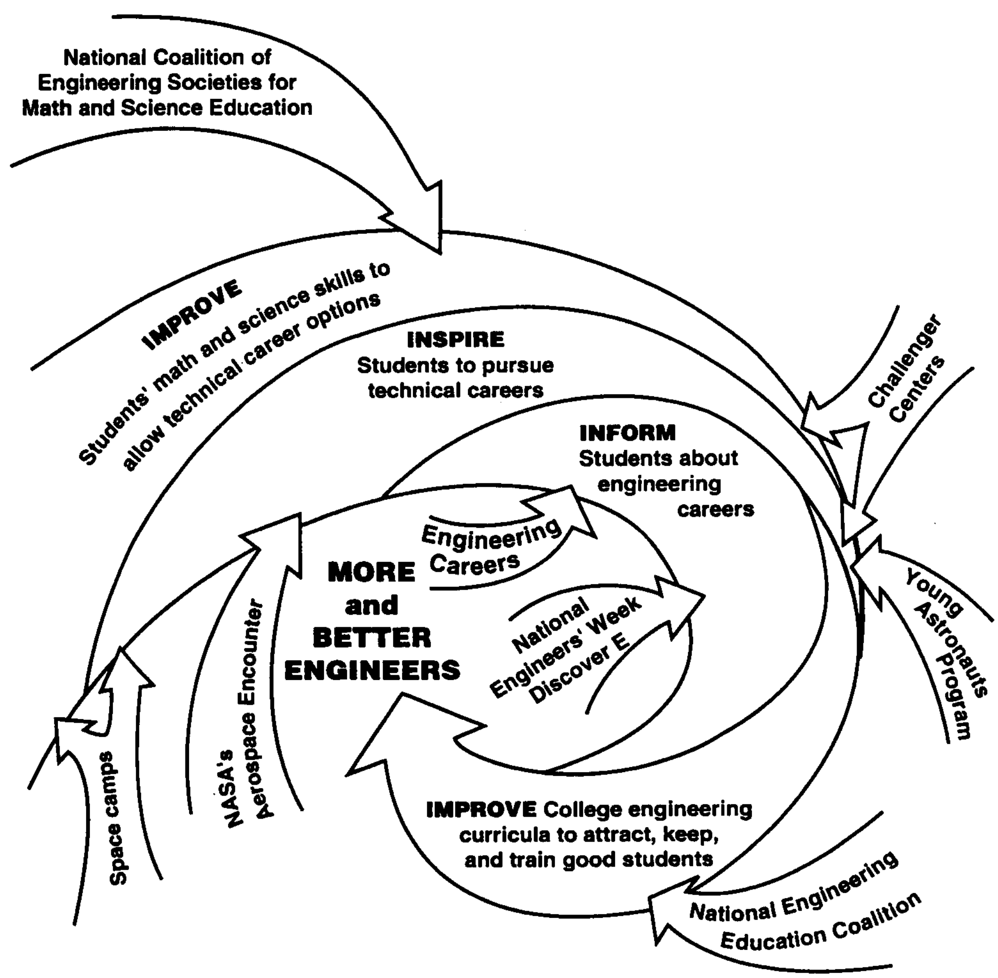


Figure 1. Engineering Careers and other programs target students in complementary ways along the path to producing more and better engineers.

The authors have twice taught an engineering careers course to high school students in California's "Silicon Valley." Nearly every student gave as the reason they took the course: "I *might* be interested in being an engineer...but first I want to find out what engineering is all about." Because our Silicon Valley students (many of whom had an engineer parent) lacked this information, we suggest that high school students in less technology-oriented areas in this country are even less able to make an informed decision to choose a career in engineering.

Across the country, engineers can balance the intangibility of "inspiration" with the substance of "information." Engineers can teach--*uniquely*--what engineering is and who engineers are. Today's engineers need good tools to inspire and inform tomorrow's engineers. This paper describes the tools the authors used in a self-contained, integrated course of study that we developed and taught in a junior college program for high school students.

LEARNING ABOUT ENGINEERING

Engineering Careers at Foothill College

Engineering Careers, the course described in this paper, is part of the Foothill Summer Youth Programs. These programs provide 8th through 12th grade students with academic challenge in a college environment; all classes offered in the Summer Youth Programs are part of the college curriculum and supply college credit. A proposal for a course entitled *Engineering Careers* was developed by M.A. Farrance and accepted by Program Director Janice Carr in 1989. In the summers of 1990 and 1991, Foothill College offered the course as part of the Space Sciences Youth Program, co-sponsored by the Mathematics and Applied Science Department, and taught by Farrance. Both authors have worked on course improvements. We expect to offer the course again in 1992. The course syllabus is shown in figure 2.

Engineering Careers is a 12-hour course offered for one college quarter unit of credit. In 1990 the class met twice a week in two-hour sessions for three weeks; in 1991 we changed to four one-hour sessions each week for three weeks. Class size and grade levels of students are shown in figure 3.

Course objective(s)– Objectives for the course are stated in terms of what we expected students to accomplish. They were told that by the end of the course, they would be able to:

1. identify a variety of engineering career disciplines;

2. identify what kinds of work can be performed by engineers in different disciplines;

3. understand by example how engineers typically approach physical engineering problems (that is, by setting up a problem model and using algebra, trigonometry, calculus and physics as tools for problem solution);

4. identify some college course work necessary to obtain an engineering degree;

Engineering Careers

Session	Topics Covered	Assignment
1	Introduction "A job" vs "a career" Making career choices; the significance of doing work that one enjoys "Engineering" and "science"	Complete Strong Interest Inventory[2]
2	Engineering disciplines Engineering functions Video: "Turning Ideas into Reality"[4] Confirm research paper topics	Read "Proud to be an Engineer"[3]
3	Engineering Disciplines Where engineers work	Deadline to return Strong Interest Inventory
4	Guest speaker	
5	Problem solving in engineering The engineer's toolbox Video: "Techniques for Visualizing Flight Dynamics"[5]	Deadline to return orientation completions
6	Problem solving in engineering	
7	Guest speaker or field trip	Read "Earning the Title of "Professional Engineer"[5]
8	Academic preparation for an engineering career The Professional Engineer The entrepreneurial engineer	
9	Guest speaker	Read "The Coming Crisis in Aerospace Employment?"[7] and "The Interdisciplinary Team"[8]
10	The engineering roles of the technical team The future of engineering Video: "Journey into Tomorrow"[9]	
11	Guest speaker	
12	Engineering a science satellite system Video: "Fast Forward to the Future"[10]	Deadline to turn in research papers and book reports

[2] Strong, E.K., Jr.; Hansen, J.C.; and Campbell, D.P., *Strong Interest Inventory*, 1991.
[3] Gardner, Dana, Design News Magazine, 11 June 1990.
[4] National Engineers Week DiscoverE, 1991.
[5] NASA Ames Research Center, 1989.
[6] Jenner, J.W., and Farrance, M.A., 1991.
[7] Supplement to *Aerospace Engineering Magazine*, January 1990.
[8] Jenner, J.W., and Farrance, M.A., 1991.
[9] Lockheed Missiles and Space Company, 1990.
[10] NASA Ames Research Center, 1990.

Figure 2. *Engineering Careers* course syllabus.

5. understand that different engineering disciplines work together in engineering projects; and

6. use newly acquired research skills to learn about *any* career choice that might interest them.

Students were evaluated for a grade based on their independent research papers, book reports, class attendance, and class participation. The instructor determined if the students met the course

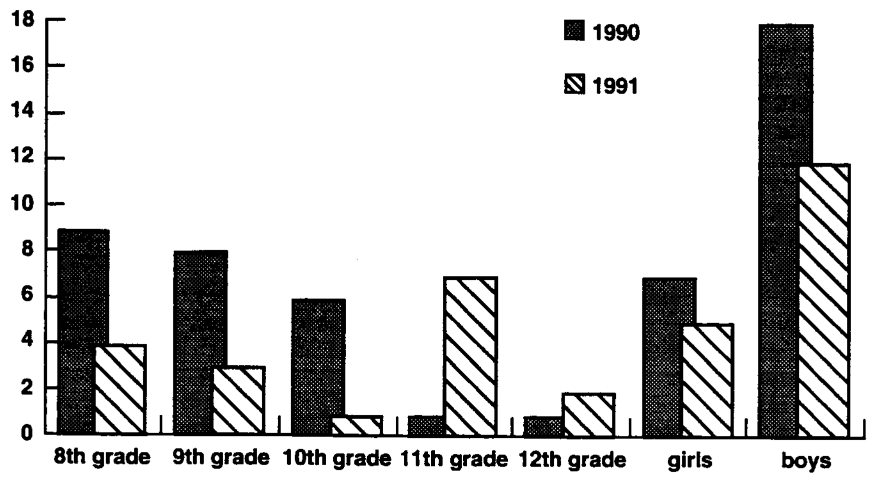


Figure 3. *Engineering Careers* class composition.

objectives by evaluating their papers and reports, in-class question-and-answer sessions, class discussions, and individual student interviews. We intentionally structured the class to avoid requiring students to memorize information that is easily available in references.

Criteria for success– Our criteria to determine the success of the course were the following.

1. More than 15 students would sign up for the course;

2. At least 90% of students would indicate an increased awareness of what engineering is, and what engineers do, at the conclusion of the course;

3. At least one student would indicate an interest in pursuing an engineering career after the class;

4. More than one-half of the students would indicate a willingness to recommend this course to their peers.

Tools for Teaching/Means for Learning

Students learned about engineering through lectures, reading materials, video, in-class activities, and independent assignments, described below.

Lectures/reading materials/video– The instructor presented lectures, some with supplemental reading assignments and videos, on topics as shown in figure 2.

The instructor used videotapes to stimulate class discussions about how the engineers featured represented their profession in various disciplines. Another short, technical tape was used with a lecture about "the engineer's toolbox" to illustrate how computer-generated graphics can be used by engineers.

In-class activities– There were two types of in-class group activities. The first was designed for self-discovery. The second provided a glimpse of how engineers use math and physical science to solve real-world problems, that is, "what engineers do."

Self-discovery exercises: One self-discovery exercise was used to help students place "education" and "work" into the context of their projected lifetimes. "This is Your Lifeline" was used to represent students' lifetimes graphically on a timeline (fig. 4). After students completed their individual lifelines, the class discussed the relationship between education and employment options, how fast technology changes, and how technology changes might affect the need for continuing education. We particularly stressed the significance of how much of the lifeline graph was filled by working years. A typical person is likely to spend 30 years—or more—working. This was compared with the 17 years that one might ultimately spend in school before earning a bachelor's degree. This comparison proved to be especially meaningful to students, who have already spent the majority of their years in school, some of whom expressed feeling "as if it will never end!" In that context, the importance of spending 30 years doing things that one enjoys becomes significant.

The authors feel strongly that self-knowledge is a prerequisite for a sound career choice. The *Strong Interest Inventory* was used to help students learn more about their own interests, and to compare their individual patterns of likes and dislikes to those of a wide variety of working adults. An in-class discussion about the individual results of the *Strong Interest Inventory* gave students an opportunity to discuss some possible reasons behind some of the correlations to professionals' profiles, and interpret their results in the context of career planning.

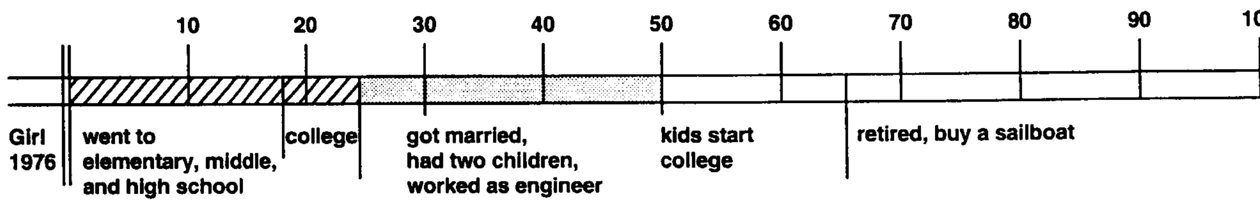
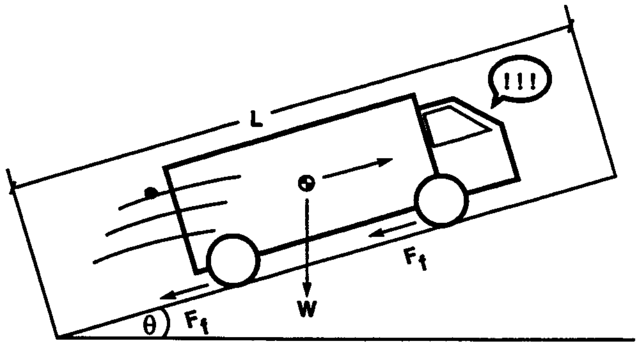


Figure 4. "This is Your Lifeline" student graph.

Engineering exercises: To learn about the use of mathematics and physical science as engineering tools, the class worked out a solution to a problem based on one posed by Smith, Butler, and LeBold, shown in figure 5. All students were unfamiliar with one or more of the techniques demonstrated. As each new element of the problem was introduced, the instructor explained the basic math and physics principles behind it. Students who had already learned the algebra, trigonometry, or physics were called on to help explain how each was being applied.

Independent assignments– Independent assignments helped students learn about various aspects of engineering and gave them a chance to practice written communication skills that engineers use in their work environments. The importance of communication in engineering was heavily stressed.

These assignments included a research paper about an engineering discipline (see fig. 6), and two letters of inquiry. Each student sent one inquiry to a university offering an appropriate engineering degree, and the other to a company or agency that employs engineers in the discipline selected.



PROBLEM (Part 1): The potential for expensive damage caused by runaway trucks on a particular long, steep downgrade is high. What is a simple and effective way to minimize damage that might be caused by runaway trucks?

POSSIBLE SOLUTIONS: (suggested by students)
- **design new trucks**
- **design new brakes**
- **redesign highway slope**
- **put center divider in road**
- ***put in up-ramp next to highway**

PROBLEM (Part 2): How long does the up-ramp have to be so that the speeding truck will roll to a stop?

ASSUMPTIONS

15% grade = 8.5 deg
gravel-covered, coefficient of friction for gravel = 0.20
initial velocity of truck = 100 m/hr

Figure 5. To solve this basic physical engineering problem, the students learned to apply some universal techniques of engineering problem-solving, such as drawing free-body diagrams, making assumptions, calculating forces, and checking solutions.

A report on a book about engineering was also assigned. Students selected a book from the course bibliography (fig. 7).

To assist them with their research, students were introduced to the Foothill College Library and the Career Center through required individual orientations with the reference librarians. These

Engineering Careers

TOPIC OF PAPER

Name the engineering discipline or field you have chosen.

DESCRIPTION OF FIELD

Describe this field of engineering. What does it include? Are there specializations within this field of engineering? What kind of work do people in this field do? Describe the kinds of products these engineers produce in the various specializations.

EDUCATION

What education is required for a degree in this field? How many years of college does it usually take to get the appropriate degree? Give two required technical courses needed for a degree in this major. Describe what these courses are meant to teach. Why do you think they are required? What high school classes are helpful for preparing for college course in this major? Name two colleges or universities that offer a degree in this field.

EMPLOYMENT

For what kinds of companies, government agencies, or institutions are people in this field likely to work? Name two companies, agencies, and institutions that might hire an engineer who has just graduated with a degree in this field.

PROFESSIONAL DEVELOPMENT

Find an article from a journal or periodical publication that might be of interest to this type of professional engineer. Give its title, author, name of the publication, and date of issue. Explain why a professional engineer might find this article interesting. Include a copy of the article with your paper.

PERSONNEL OBSERVATIONS

Does this field appeal to you as a career choice, or not? If yes, why is it interesting? If no, what do you find unappealing, and what field would you research next? How does this field match with the results of your interest inventory? Does the interest inventory indicate that you might like working in this field? Why, or why not?

REFERENCES

Use the Foothill College Semans Library, Career Center, and any other resource you want. List the sources of your information (books, encyclopedias, periodicals, college catalogues, Eureka database, etc.)

Figure 6. Research paper outline.

The Civilized Engineer, Florman, Samuel; St. Martin's Press, 1987
Structures, or Why Things Don't Fall Down, Gordon, J.E.; Plenum Press, 1978
Freedom to Soar, Kimball, J.B.; Kimball Publishing, 1989
Ethics and Professionalism in Engineering, Mantell, M.I.; MacMillan, 1964
Psychology of Everyday Things, Norman, D.A.; Basic Books, 1988
Beyond Engineering, Petroski, Henry; St. Martin's Press, 1986
Women in Engineering, Posner, Alice; Career Horizons, 1981
Engineering as a Career, Smith, R.J., McGraw Hill, 1983
The Encyclopedia of How It's Built, Clarke, D., A&W Publishers, 1979

Figure 7. *Engineering Careers* course bibliography.

assignments gave them practice in using research resources: the on-line catalogue, the reserve library, college and university catalogues, newspaper want ads, the periodicals index, and the Eureka careers information database.

Guest speakers – We invited engineers from the local area to talk to the class. We made a deliberate effort not only to have the speakers represent a variety of engineering disciplines, but also to introduce students to enthusiastic, articulate engineers of both sexes, with varied backgrounds. To increase the chances of a successful interaction with the students, both the guest speakers and the students were prepared in advance by the instructor. Students were reminded that part of their class grade was based on "class participation," including interaction with the guests, and some class time was spent before speakers' visits to generate some questions to ask each of them. Guest speakers were provided with some orientation material supplied by the instructor. A sample is shown in figure 8.

Engineering Careers

Try to include the following information in your presentation:

What is your job? (Tell them your title, but also tell them what you do.)
Describe a typical day.
What kinds of tools do you use in your work?
Why did you choose engineering/your particular discipline?
Do you belong to any professional societies?
Will you stay in engineering, or are you considering a change?
What do you like best about your job? What do you like least?
Where did you go to school? How did you pick that school?
How did you get your first job?
How long have your been working?
How many different jobs have you worked at? How many different companies?

Be prepared to answer the folowing question. Students almost always ask:

How much money do you make?

The best answer to this question is not necessarily a number, but rather a relative assessment of how your salary affects your standard of living. Is your salary enough for you to afford a house? Pay for leisure activities? Not as large as your friend's, who is a doctor/lawyer/computer programmer? Larger than another friend's, who is a travel agent?

Please use visual aids: overhead transparencies, videotapes, pictures, show-n-tell hardware, printouts, drawings, etc.

Encourage questions. Ask questions of them, and listen to their responses.

Use personal anecdotes. Have at least one good story ready.

Figure 8. Suggestions made to guest speakers.

CONCLUSIONS

Meeting the Success Criteria

We obtained student feedback from a course evaluation (fig. 9) and student interviews. From this information we determined that this course had met our success criteria.

1. We had 25 students in 1990 and 17 students in 1991 complete the course;

2. 100% of students indicated an increased awareness of what engineering is and what engineers do at the conclusion of the course;

Engineering Careers

Was this a worthwhile course for you? Why or why not?

Was the level of work required appropriate?

too much	about right	too little

Was the lecture and class material appropriate?

too much detail	about right	not enough detail

Was the number of guest speakers appropriate?

too many	about right	not enough

Was the variety of guest speakers appropriate?

too many	about right	not enough

What did you like BEST about the course?

What did you like LEAST about the course?

I would like to improve this course. What do you recommend that I do to make it better?

Would you recommend this course to a friend? Why or why not?

Figure 9. Course evaluation form.

3. 44% of students indicated that the course helped them decide to pursue an engineering career (one former student is currently working as an intern at NASA Ames Research Center and plans to major in engineering next year);

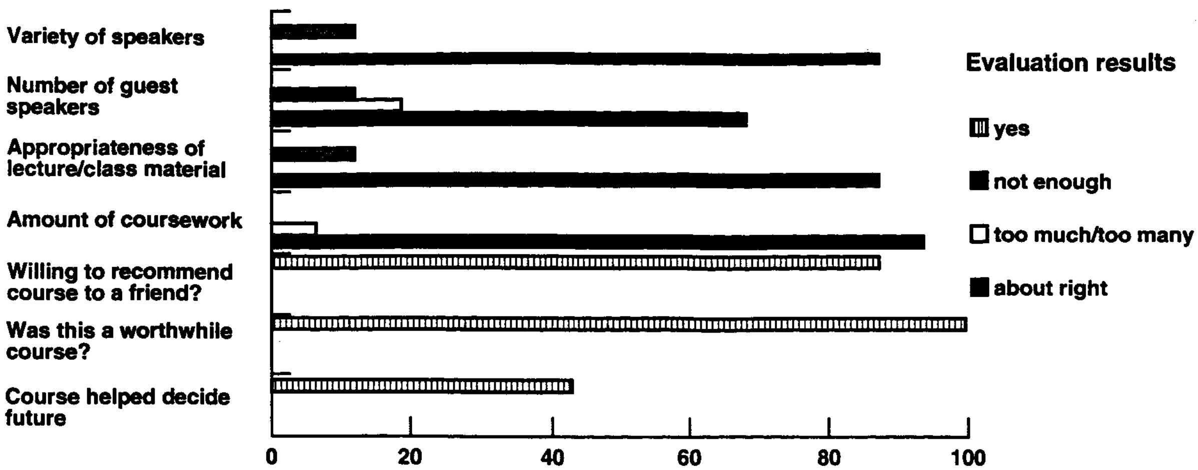
4. 88% of students (100% of the students who answered this question) indicated a willingness to recommend this course to their peers.

Additional student feedback about the course is given in figure 10. We are making improvements to the course based on both feedback from students and our own observations.

What Worked

From the student's point of view– The activities that students liked most were those that required student involvement, in particular, the self-discovery exercises and the engineering problem. Frequently mentioned were the guest speakers. Guest speakers who brought items for show-and-tell had good student involvement. (See fig. 11.)

No student actually claimed to have liked doing the book report, but several students reported that they had read a book they would not have found or read otherwise, and enjoyed it. Most books met with the students' approval. *The Civilized Engineer*, by Samuel Florman, was the most popular.



"The guest speakers gave us a good idea about what engineers do."

"I probably wouldn't have done as much research and reading about [engineering] as I've done here."

"This course let me learn more about the different career choices in engineering."

"I would recommend this course because it helps a person have a better perspective on whether he/she wants to become an engineer."

"[This course] helped me make up my mind to go into software engineering."

"Now I have a better idea of what the different types of engineers do so I can better decide what area I want to major in."

"[This course] showed me what kinds of careers there are, and what I might be good at."

"This class was very worthwhile, even to get up at 6:30 for. It helped me decide what I want to major in once I go to college."

"[This class] really taught me a lot about engineering. I learned more than I ever could back at high school. It really broadened my horizons. I think I've finally decided what I'm going to do with my life: become an aerospace engineer!"

"I learned what I wanted to and I know about the fields of engineering now. I'm seriously considering a career in engineering."

Figure 10. Student evaluation results.

From the instructor's point of view– The learning value of the engineering exercise was not *what* problem we worked, but *how* we worked through it. The explanations of each element of the problem helped illustrate how engineers approach problem-solving.

The judicious use of selected technical materials such as videotapes and drawings was found to be highly effective for teaching. The access to such material, along with the ability to explain in basic terms what it is and how it's used, is unique to the engineer-as-teacher.

Student orientations with the library and career center worked well. This requirement was added in the second year of the course, because many students in the first course did not take advantage of

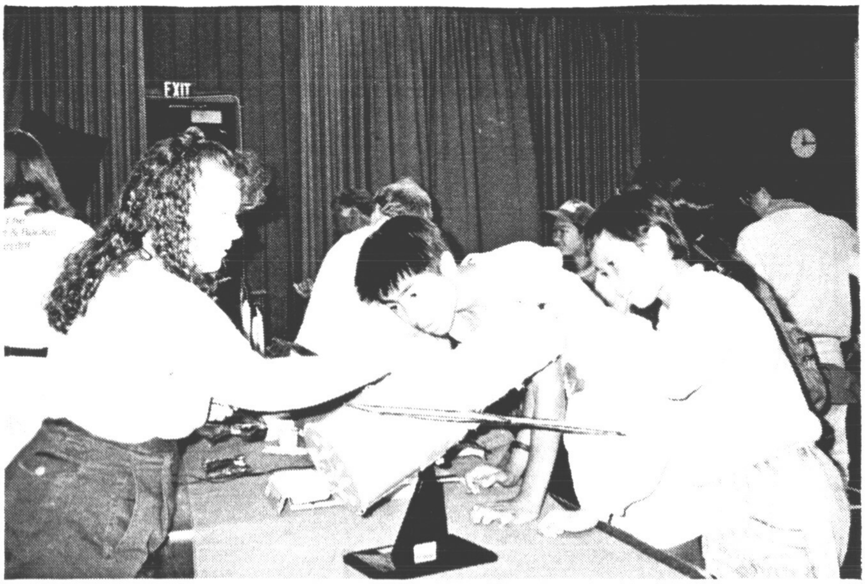


Figure 11. Students particularly enjoyed guest speakers who brought items for "show-and-tell" and encouraged student involvement.

these resources when they were not required. The cooperation of the librarians at Foothill College reminded us that librarians in general are happy to help people learn to use resources and need only to be asked.

We found that the value of the self-discovery exercise is primarily in the discussion about the results. The *Strong Interest Inventory* is not the only self-discovery exercise appropriate for high school students; others are available or can be developed. Our first year students completed a different inventory based on an exercise from SPACES.

What Didn't Work—Room for Improvement

The student's inquiry letters to companies that employ engineers did not always produce a satisfactory response; many replies were form letters. Student evaluations indicated that straight lectures (those without student reading preparation or exercises) were uninteresting and did not involve them enough.

Recommendations

Engineering Careers 1992

We are making the following changes to the course, consistent with suggestions by students.

1. Develop more written material for student reading assignments, especially on engineering disciplines and functions, and shorten lectures.

2. Add at least one class engineering project as an extension of the problem solving exercise. For example, in the case of the truck-ramp exercise, the class might test their chalkboard solution by rolling vehicles down a ramp of the same slope as the hill in the problem and determining (after scaling the distances) how far up the second ramp the vehicle will travel after it has accelerated down the "hill."

3. Increase class duration to six weeks (a total of 24 hours of class time) to allow time for in-class engineering projects.

4. Retain the one-hour-session format. Students and instructor both found the shorter sessions easier for their attention spans.

5. Add options from which to choose for a second project. We hope to provide students with more opportunity for communication practice. Options will include book reports and presentations to the class on some engineering topics.

6. Send the inquiry letters early and have students bring in the replies to share with the class.

Adapting Engineering Careers to Other Settings

Based on our own observations and feedback from students who have taken *Engineering Careers*, this course appealed to a range of ages, from 8th to 12th grade level. That is, it was not too difficult for the youngest class members nor too simplistic for the older class members. Eighty-eight percent of the student evaluations indicated "I would recommend this course to a friend." Our plan is to continue to offer the course through Foothill College, and we would also like to encourage others to use what has worked for us. We feel, however, that this course is appropriate for students who are already interested in math, science, and technical subjects. Without major changes, it is not likely to appeal to "at risk" students who are already uninterested in school, or with students below an 8th grade level.

Engineering Careers might be used in slightly modified form for programs in which students meet regularly and explore an interest in science and technology, such as Young Astronauts or Scouts. It might also be adapted to a regular high school class setting with a well-motivated class, such as an honors course in physics.

Individual exercises from *Engineering Careers* can be used in other contexts. The chalkboard engineering exercise might be used to illustrate engineering problem-solving techniques, but we emphasize that this exercise should be reinforced with hands-on activity. The independent assignments can be used in almost any setting where students meet at least twice and can earn some type of reward for their effort (such as a grade, a merit badge, or an award).

Finally, our techniques for preparing both students and guest speakers have provided good results. We encourage teachers to invite engineers into their classes, and we encourage fellow engineers—especially women and minority engineers—to volunteer to speak to students. Engineers who both inspire and inform young people about engineering literally are helping to "engineer the future."

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BIOGRAPHIES

Michelle (Mickey) Farrance is a mechanical systems engineer developing Space Station *Freedom* environmental science research payloads for NASA Ames Research Center as an employee of G.E. Government Services. She has previously worked on *Freedom* design and mechanical interface coordination for Lockheed Missiles and Space Co. Since 1982, she has taught space science and engineering courses for the California Academy of Sciences, Girl Scouts, Young Astronauts, and most recently Foothill College. She is currently completing an M.S.M.E. at Santa Clara University.

Jeffrey Jenner is a mechanical engineer responsible for development of biological research equipment for Space Station *Freedom* and is employed by NASA Ames Research Center. For the past ten years, he has worked on several NASA and Air Force spaceflight programs, designing ground support facilities and testing spaceflight hardware. He has worked with high school and college students in various internship programs. He is currently completing an M.S.M.E. at Stanford University.