CHAPTER 8

TEACHING WITH TECHNOLOGY

This chapter also focuses on the how-to of teaching, except that here technological means are used to deliver the instruction. The delivery media include television and video, computer and laser videodisc, and audiotutorial. Many different teaching *methods* such as lecture, interactive tutoring, discussion, and drill can be used with different delivery media. Television and video are discussed first because these media are often used with the traditional lecture method of Chapter 6. In universities, educational television has been used to deliver lectures to remote sites or at different times. Television and video are also useful as backups for live lectures and for providing feedback to students. A computer can be used as a tool to reduce the repetitive nature of calculations (see Sections 8.2.1 and 8.2.2 on spreadsheets and equation solvers and simulation programs), while most of the teaching uses traditional teaching methods and a live delivery medium. A computer can also replace the traditional live delivery through computer-aided instruction (Section 8.2.3) or interactive laser videodisc (Section 8.2.4). The audiotutorial technique involves a combination of technology, laboratory, and other teaching methods.

In this chapter it is necessary to draw a distinction between the teaching method and the delivery medium (see Figure 8-1). A teaching method (lecture, discussion, drill, etc.) is chosen and then paired with a delivery medium (live interaction, live TV, videotape, noninteractive computer, etc.) to reach the learner. The general flow sheet is shown in Figure 8-1a, and specific applications are shown in Figures 8-1b to 8-1g. In Chapters 6, 7, 9, and 10 the delivery medium is usually live interaction. In this chapter various technological media are used to deliver the instruction.

Over the years, the introduction of new technology for education has generated initial high excitement, but that has been followed by disillusionment, although eventually most technologies find a niche in the educational system. Throughout this chapter we will consider what delivery of instruction by technological media can do better than the nontechnological
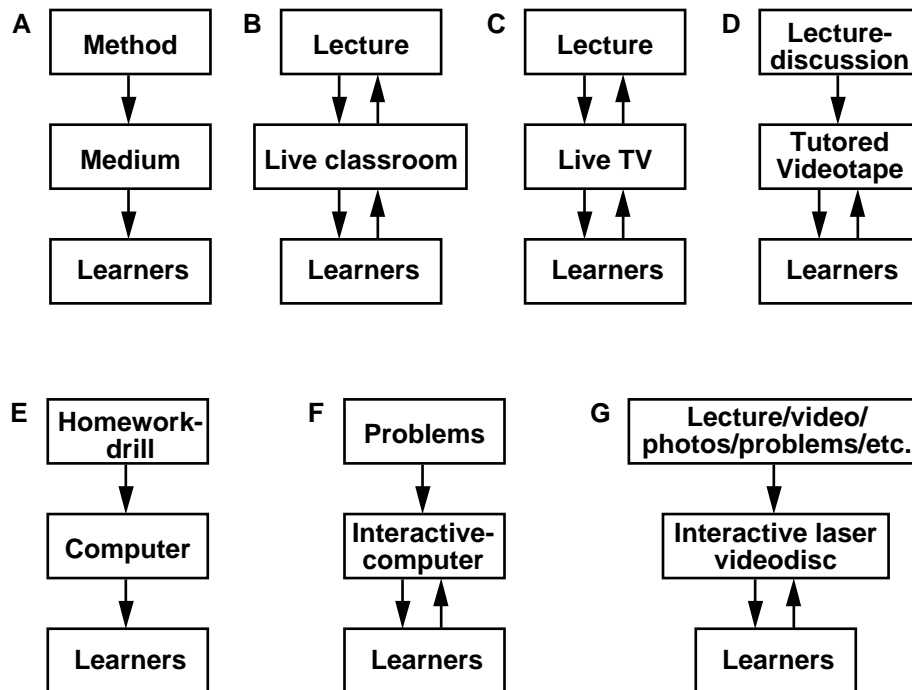
FIGURE 8-1 INTERACTION OF TEACHING METHODS AND DELIVERY SYSTEMS.
A. General flowsheet. B. "Normal" lecture (Chapter 6). C. Live TV (8.1.1) D. Tutored videotape (8.1.2). E. Non-interactive CAI drill (8.2.2). F. Interactive CAI (8.2.2). G. Interactive laser videodisc (8.2.3).

delivery alternatives such as lecture, discussion, cooperative groups, and PSI. Gibbons et al. (1977) present the following list of guidelines for the successful use of technology in education:

1 Plan use for a specific audience.
2 Define objectives which are relevant to the audience.
3 Pick a technological medium and a teaching method which are appropriate to the topic.
4 Pick educators interested in using the technology.
5 Plan for personal interaction, particularly among students.
6 Monitor the course and change materials and methods as appropriate.

Of course this list can be applied to any teaching method if the words "teaching method" replace "technology." If use of the technological medium does not have an advantage as compared to nontechnological delivery, the combination of technological delivery medium

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and teaching method will probably not survive after the innovator has moved on to other activities.

8.1. TELEVISION AND VIDEO

We will discuss television and video as delivery media for the education of engineering students (Section 8.1.1), describe a particular form of instruction with video called tutored videotape instruction (Section 8.1.2), discuss the steps the professor should take to improve television teaching (Section 8.1.3), and finally, briefly consider the use of television as feedback for students (Section 8.1.4).

8.1.1. Instructional Delivery by Television and Video

What can delivery of instruction by television or video do better than other means of delivering instruction? First, television and video make it possible to provide instruction at remote sites. This ability has been extensively used for continuing education and graduate programs for engineers employed in industry away from universities. Second, television can be used to break a huge class into much smaller sections. Third, videos provide flexibility in that they can be observed at any time. And fourth, a professor can use them to make "electronic" field trips to observe technology.

"Distance education," or the use of television and video to deliver instruction at remote locations, has become important in both continuing education and graduate education as well as in many fields in addition to engineering. It has even spawned *The American Journal of Distance Education* (Penn State University, 205 Rackley Building, University Park, PA 16802). Both live television delivered by satellite and video are used, although the applications are somewhat different. Most universities that have used television have used it for graduate-level courses. Practicing engineers can continue their education to a master's degree with minimal disruption of their careers and of their family life. Seigel and Davis (1991) also found increasing acceptance of television for undergraduate engineering courses, and thirty-nine of the schools surveyed allowed this option. On a national scale, the National Technological University (NTU) collaborates with many universities to present a wide variety of live broadcasts most of which are of interest to engineers and scientists. These vary from single two- to three-hour broadcasts for continuing education, to three-credit courses, to ninety-hour certificate programs, to masters programs in engineering. For more information write to the National Technological University, 700 Centre Ave., Ft. Collins, CO 80526. The Public Broadcasting System (PBS) has televised college-level courses since 1981. Almost 2 million students have earned credit toward undergraduate degrees at a variety of universities (Anonymous, 1991). Unlike the courses at the NTU, the PBS courses are of much more general interest, and PBS is not the credit-granting institution.

Live educational television in engineering has usually employed a teaching method where a professor lectures in a television studio. Often there is a live audience of students taking the course for credit at the university and at a number of remote sites. A typical studio has a camera for the professor, an overhead camera for the notes the professor writes on a tablet, and a camera for the audience. Students in the studio audience can ask questions of the professor, and their questions are picked up by microphones so that the remote sites can also hear them.

The remote sites usually have some form of two-way communication with the professor. The most common form is two-way audio over telephone lines with speaker phones. This is certainly the cheapest form of two-way communication, and in most instances it is adequate. In engineering some form of visual feedback is also very useful since it is difficult to discuss equations or drawings with audio alone. An electronic blackboard such as the AT&T Gemini 100 is one option (e.g., Gupta, 1981; Walker and Donaldson, 1989), but it was not widely adopted by schools and is now obsolete. Audiographics has proven to be a more acceptable technology for interactive delivery of both audio and graphics to remote sites (Chute and Elfrank, 1990). Audiographics uses networked personal computers to transmit text and graphics. Speakerphones can be used for two-way voice transmittal while television provides visual and audio transmittal, but audiographics can be used without the television link. A third option which is useful for equations is electronic mail, but this has also not been widely used since many remote sites are not on networks. Fax could be used, but the transmission delay might be a problem. Perhaps the best, but most expensive, solution is two-way video which is used by Washington State University (Howard and Peters, 1986). This example illustrates a common problem in education: An adequate technology is used because it is significantly cheaper than a technology with fewer limitations.

The television delivery system must be of high quality (Canelos and Mollo, 1986). This means that a professional-quality studio must be available. It is not feasible to do high-quality television or video without professional-quality equipment. The downlinks from the satellite must also be of professional quality for live television. These requirements mean that television courses are expensive. Live television becomes cost-effective when a large number of sites share the same broadcast. For a single remote site it is probably cheaper to have the professor travel to the site or to use video instead of live television. The quality of the professor's presentation is also critical, and this is discussed in Section 8.1.3.

The major instructional difficulties with live television are the lack of contact between the students and the professor, and the cost and difficulty in doing anything other than "straight" lecturing. Television can be an impersonal environment for learning. The term "distance" applies to psychological distance as well as geographic distance. Field-sensitive individuals in particular will have more difficulty adjusting to a television course. (See Section 15.2.1) Since the majority of engineers are field-independent, this will be less of a problem in engineering than in other fields. Still, the professor needs to do whatever is feasible to create a sense of contact and to help build rapport. Visits to the remote sites during the semester can help tremendously. Professors can also have phone office hours every week, although many students will not take advantage of this opportunity. Discussion and questions are more difficult in a live television course even with the students in the studio. Thus, the professor must increase the effort made at soliciting and answering questions. Television encourages student passivity, which is not productive for learning.

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Television excels at showing visuals; unfortunately, most engineering programs do not take advantage of this characteristic. For example, a course in structures could include video of the site before, during, and after construction of a building or bridge. A course in robotics could show an actual assembly line in operation before and after the installation of robots. With planning and organization appropriate visuals can be included. For example, the professor can take a hand-held video camera to a construction site or into a plant. With some modest editing the result can be used as part of the television broadcast for both local and remote sites. Full utilization of television requires some creativity on the part of the professor.

Television and videotape classes on campus have the advantage of additional flexibility for students. If a student cannot schedule the class, he or she can always watch the videotape at a more convenient time. We had this experience in a live television class. Halfway through the semester a student was unable to attend the lectures, but he was able to keep up with the class by watching a videotape of the live broadcast. In addition, he presented an oral report to the class on videotape. Since finals were scheduled separately, he was able to take the final with the rest of the class. Although not widely used, videotapes could also be helpful to students with limited mobility who might prefer to watch a video in their homes rather than come to the campus every day.

Videotapes can also be useful supplements to other classes. A videotape can show how a laboratory experiment should be done (e.g., Kostek, 1991). Then instead of each group being shown how to do the experiment when it is their turn, they can be handed the videotape. We have used this procedure with good results even though the videotapes were homemade. Since the students were very motivated to learn from the tape and since they watched it in groups of three, the homemade character of the tape was not a problem. Videotapes of the apparatus or of various pieces of equipment can also be made to save time in the students' getting-acquainted process before the experiment begins. They can also be very useful for electronic field trips. In a biochemical engineering class, for example, students can use a videotape to observe the operation of specialized and often delicate equipment (Austin et al., 1990). Once produced, the videotape can also be used at schools which do not have the equipment but want to present an up-to-date course. Druzgalski (1988) notes a similar application where biomedical equipment and techniques can easily be videotaped and shown to classes which might not otherwise be able to see the procedures. Squires et al. (1991) used company-produced videotapes of plant tours to show students a chemical plant without the time and expense of a field trip. The advantage of involving the companies was that once they decided to support the videotape they paid for a professional company to produce it. These tapes can then be used at many schools to justify the production costs. Other applications of videotape supplements to other teaching methods await the ingenuity and energy of individual professors.

How well do students learn from television or video courses? Based on a variety of studies, the answer is that there are no significant differences between student learning from either television or video and from more traditional courses (Canelos and Mollo, 1986; Chute and Elfrank, 1990; Gibbons et al., 1977; Moore, 1990; Scidmore and Bernstein, 1986; Walker and Donaldson, 1989; Wergin et al., 1986). Although some studies have found that on-campus students do better, others have found that off-campus students do as well or slightly better. The net result is that the medium used is not critical. Much more important are the quality of the delivery and the message.

8.1.2. Tutored Videotape Instruction

The other system which has been used extensively for the delivery of classes to remote sites is tutored videotape instruction (TVI) which is illustrated in Figure 8-1d. This method was originally developed at Stanford University (Gibbons et al., 1977). With this technique a video is produced on campus by essentially the same procedures as live television. It seems to be most effective if the video is made of a live class. The video is then shipped to the remote sites where it can be shown at a convenient time. When the video is shown at a remote site, a local engineer who is qualified to help teach the material serves as a tutor. The video is shown for roughly five to ten minutes and then halted for questions and discussion. The next segment of the video is then shown followed by a question-and-discussion period. This procedure is repeated until the video is finished. The tutor may discuss example problems at any time. If there is a time constraint on class length, the video should be about thirty minutes long so that there is time for the questions and discussion. If the tutor is unable to answer any questions, the professor can be called on the telephone at prearranged times. This is apparently rarely necessary. The professor prepares homework and examinations, sends them to the tutor, and then supervises the grading after the tutor returns them.

This procedure is more flexible than live television and has more live contact except that the contact is with the tutor instead of with the professor. Groups should have from three to ten students with the optimum size appearing to be from three to eight students. This procedure can then act as a cooperative learning group (see Section 7.2.2) and will have the advantages of cooperative groups.

The selection of tutors is important. Gibbons et al. (1977) suggest that tutors at remote sites should be:

1 Practicing engineers at the site.

2 Have a personal interest in reviewing the subject but not be so expert that they will be bored by the tapes.

3 Have a desire to help teach the course.

4 Be sensitive to the needs of the students and able to draw them into discussion. Tutors with a discussion style are more effective than tutors who want to answer all the students' questions.

Tutored videotape instruction has also been used to advantage on campus (Gibbons et al., 1977; Robinson and Canelos, 1989; Scidmore and Bernstein, 1986). TVI allows the school to offer a course even when the professor is not available because of sabbatical or other commitments. Graduate students are happy to serve as tutors and probably find the assignment more enjoyable than being a grader. For on-campus applications of the method Scidmore and Bernstein (1986) found "as much, if not more, success with undergraduate tutors as with graduate student tutors. Undergraduate tutors have frequently just completed the course and are closer to the students' problems than a graduate student." TVI has also been used in undergraduate classes to break supersized classes down into much more manageable sections. With a tutor assigned to each section the students have the benefits of contact and of seeing

the professor lecture on the material. Since small classes are always appreciated by students, this application of TVI should receive particularly high student ratings if the class size is kept within the suggested range of three to ten students per section.

One possible abuse that does not occur with live television is failure to update the videotapes. Once prepared, tapes often continue to be used even though they may have become outdated. TVI can also be abused if the professor who produces the tape abandons the class or if sections are allowed to grow too large in order to keep tutor costs down.

The TVI method appears to be a very effective instructional technique. Gibbons et al. (1977) found that TVI students performed better than students in live lecture classes, who performed better than students in live TV classes, who performed better than students in video classes without a tutor; but the results were not statistically significant because of the small numbers of students in the sample. There was also evidence that the poorer students benefited most from the TVI teaching technique. Gibbons et al. (1977) hypothesized that the small class size and the ability to interrupt the lecture frequently for discussion were more important factors in the success of the method than the use of videotape. (That is, the method was more important than the medium.) Scidmore and Bernstein (1986) compared on-campus TVI students to on-campus students in lecture courses. For three years of use in sixteen sections spread out over three different electrical engineering courses, the TVI students consistently averaged better on a comprehensive final examination than did the lecture students.

8.1.3. Instructional Hints for Television and Video

As with all techniques and classes, it is the instructor who controls the quality of instruction. Obviously, with television and video there is the added requirement that the production must be well done. Production details are discussed by Canelos and Mollo (1986) and Yoxtheimer (1986). However, even great production facilities cannot compensate for poor instruction. The following hints are from Canelos and Mollo (1986), Garrod (1988), Yoxtheimer (1986), and our personal experience.

1 Be prepared and well organized. Since television magnifies problems, you must be prepared and organized.

2 Arrive early at the studio. Extra time is required for setting up the cameras, and the producer will become very agitated if, as the starting time approaches, the "star" of the show is absent.

3 If possible use an overhead camera for visuals instead of a blackboard. It is difficult to obtain in-focus pictures of the entire blackboard.

4 Make sure the presentation is of high quality. Material which is prepared ahead of time must be neat and carefully proofread. If you write notes as the lecture is presented, have the ideas prepared ahead of time. Write few words and few equations. Write neatly. Orient the material horizontally since television uses dimensions with a height of three and a width of four. If large quantities of written material are required, use prepared material which has been handed out to all students in advance. Be sure that the handouts are also of high quality.

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5 Use the principles of good teaching and good lecturing. Aim for variety in the presentation. A head talking in a monotone is even more boring than a boring presentation in person. Break the lecture into small parts with time for questions, discussion, and group activities.

6 Work to obtain group participation. Learn the names of the students both in the studio and at the remote sites. Allow extra time for questions from the remote sites. Repeat all questions since the microphones may not pick up student questions.

7 For feedback watch the tape. If necessary, adjust your teaching style. If the tapes will be used, edit or reshoot unsatisfactory portions. Prepare a practice tape before the semester starts and discuss your performance with a television expert.

8 In a TVI course develop written instructions for the tutors for live, in-class activities. Do not assume that they can develop these by themselves. Encourage the tutors to stop the tape frequently for discussion and other activities. Meet with and get to know them since the professors and the tutors form a team. Monitor the tutoring throughout the term.

9 Have copies of the tapes and the written materials available at the library or learning center.

8.1.4. Videotape Feedback for Students

Videotape is the premier technology for showing students how others see them. The gift which Robert Burns prayed for is now here, and it is videotape. If oral communication or interpersonal teamwork is required, videotape feedback to students is invaluable. Fortunately, such use can be relatively inexpensive. It is not necessary to have a studio, and it may be preferable not to have one. Many students are afraid to appear before a camera, and videotaping in a normal classroom is less threatening. The equipment needed includes a camera, a tripod, a VCR, and a TV monitor. In the classroom only the camera and the tripod are necessary, and it is probably better not to have the other equipment in sight. Although it is convenient to have a TA or undergraduate assistant serve as camera operator, this is not absolutely necessary. The camera can be prefocused on the tripod and then be turned on before the students start.

Procedures for videotaping oral reports are discussed by Wankat et al. (1977). First, get the students accustomed to the camera. This can be done by asking every student to make a very short, ungraded oral presentation in front of the camera. Although they may learn something from watching these short videos, the main purpose is to reduce anxiety when they make their regular presentations.

The regular presentations should follow the normal format for oral presentations in class. The reports should be timed. Students should be encouraged to use visual aids such as an overhead projector. These visuals will probably not show up on the tape, but this is unimportant since the purpose of the tape is feedback, not communication to others. Have the class ask questions and continue to videotape the speaker while he or she responds.

No one likes the sound of their voice on a tape, and many people do not like the way they appear on camera. Since the student is likely to be embarrassed, show the tape privately. Most students will be very severe critics of their presentation when they see the tape. If a student becomes upset while watching the tape, be sure to give some positive feedback and point out what worked. The camera is very blunt in showing problems, and usually there is no need to point out what is obvious to the student. Give the student a few pointers on what to do to improve, but do not overload him or her with too much advice. However, after more than ten years of taping student presentations, both undergraduate and graduate, the more common response we have seen is a positive one. Students discover that all the nervousness they feel while speaking does not show up on the tape; it's all internal—their knocking knees aren't visible for all to see. Also, they generally concede that the talk went better than they thought it would, or that they didn't sound as bad as they thought they would. For every student that is appalled at seeing himself or herself, many more enjoy watching themselves. Our favorite reaction was that of one student who sat back as he watched himself and in all seriousness proclaimed, "Damn, I'm good looking!"

Additionally, videotaping oral reports greatly improves the instructor's ability to give feedback. While watching the tape, instructors regularly see mannerisms and nuances they did not see the first time. The student also receives much more individual attention, which is important for improving presentation skills. Once students see their presentations, they seldom complain about the grade they receive on the oral report. Finally, the old adage of a picture being worth a thousand words holds very true with videotapes of oral presentations. You can tell a student over and over that he or she says "um" too often, but the impact of watching oneself "um" and "er" through fifteen minutes of material is much more powerful and immediate. The reality becomes painfully obvious.

Although much less common in engineering classes, videotapes can also be very helpful for interpersonal training. A camera is a very effective device for showing students their behavior and the reactions to their behavior in groups. In counseling programs it is common to use a room equipped with one-way mirrors so that the presence of an observer and of the camera does not disturb the group. Even without a one-way mirror, videotaping can be valuable for providing feedback. Once they get started, most groups tend to forget that the camera is there. The camera operator should attempt to be unobtrusive and should never give directions to the group. The quality of the camera work is not very important; it is much more important to capture the group in action. One problem with groups is that members behave differently at different times. It may be necessary to videotape several hours of group interaction to obtain the entire range of any individual's repertoire of group responses.

If the group proceeds well, the entire group can watch the videotape for feedback. Be sure to stop the tape at appropriate places for a discussion of what has happened. If one member of the group was obstructive, it is probably appropriate to show the tape to that person privately. Otherwise, there may be a tendency for the group to beat up on that person now that he or she cannot deny the behavior. Discuss with the student what can be done to improve her or his skills in groups.

8.2. COMPUTERS IN ENGINEERING EDUCATION

There has been a computer revolution in engineering education, but to date it has been much less far-reaching than many prophets predicted. Computers and calculators have greatly increased the ability of students (and practicing engineers) to perform calculations. Since computers and calculators allow professors and students to do a much better job at calculation, they have been widely adopted in engineering education. As a result, professors have changed the nature of the problems presented, and they have changed many of the mathematical techniques taught. This has been an important change in the way engineering is taught (and practiced). However, we have not seen significant adoption of computers for the delivery of instruction.

In this section we will first explore the use of computers as tools in the classroom. The commonly used generic computer tools are spreadsheets, equation solvers, and symbolic algebra programs. Simulation programs tend to be much less generic but will be discussed with the other tools. Then we will discuss computer-aided instruction which uses a computer to deliver instruction. Finally, interactive laser videodisc instructional methods will be considered.

Before any computer application is adopted, the professor needs to determine whether five prerequisites for instructional use of computers have been met. The first three are from Trollip (1987/88).

1 Accessibility. Both the hardware and the software must be readily accessible to both students and faculty.

2 High-quality software. The software must do something that the students want it to do, it must have clear and unambiguous screen displays, the interaction between user and machine must be easy, the software must be easy to use, the software must be relatively fast, and above all, the software must be robust.

3 Faculty interest. The faculty must have sufficient interest and energy to follow through with the project. The amount of interest and energy required depends on the project. For adopting generic tools such as spreadsheets, the amount is modest, but for writing computer-aided instruction packages it can be staggering.

4 Advantage. A computer must be able to do something better than the student can do it working without the computer. If there is no perceived advantage, then students will not use the computer and the faculty will drop the experiment.

5 Student computer background. Students must be taught how to use both the hardware and the particular software. If this has not been done in a prerequisite course, then they must be taught in the current course. Particularly for weaker students, learning about unfamiliar hardware and software in a discipline-oriented course can lead to cognitive overload and a poorer performance (Whitney and Urquhart, 1990).

8.2.1. Computer Tools

Engineering professors have recently discovered the use of generic software such as spreadsheets and equation solvers for the solution of engineering problems. As the available packages have become more powerful, robust, and user-friendly, it has become clear that they represent an extremely useful middle ground between hand solutions and computer programming. Some students will do almost anything to avoid programming, but the generic packages are user-friendly enough that, with a little training, almost all students can be induced to use them. Thus, in many applications computer tools are a significant advance over both hand calculations and programming. Because of this advantage, computer tools, particularly spreadsheets, have been widely adopted.

Students need to learn how to use the various software tools. Probably the ideal arrangement is to teach engineering students how to use the software as freshmen and then use it in all subsequent engineering courses. If students have not learned a particular software tool before it is introduced in class, most of them will not use it unless they receive help. Keedy (1988a) suggests the development of core manuals for software using the "20-80 rule." That is, identify approximately twenty concepts and the associated keystrokes which represent 80 percent of the power of the package—and everything the students need to do. When students first learn the package, they don't need to know the most efficient way to do something; instead they need to know the easiest way to learn and remember. Once the 20-80 items have been identified, write a short core manual which explains how to use these selected features. Interested students will learn other operations on their own or from other students once they know how to use the basics of the software.

Applications of spreadsheets in engineering courses have exploded since 1987, and they have been used in all engineering disciplines: for example, aeronautical engineering (Stiles et al., 1989), chemical engineering (Misovich and Biasca, 1991; Rosen and Adams, 1987), civil engineering (Anderson et al., 1988; Mortimer, 1987), electrical engineering (Lofy, 1988), freshman engineering (Genalo and Dewey, 1988; Keedy, 1988b), and petroleum engineering (Cress, 1988, 1989). Chapra and Canale (1988) show how spreadsheets can be used to implement a variety of numerical methods, and Burman (1989) illustrates the conditioning of climatic data with spreadsheets. This list of references is only the tip of the iceberg, and anyone who wants to can easily find many more.

As long as a spreadsheet has appropriate graphing and scientific function features and is fast enough, the choice of spreadsheet is almost immaterial (Lofy, 1988). In addition, students who learn how to use one type of spreadsheet can easily learn to use a different spreadsheet on their own. Thus, there is no need to worry about them seeing a different spreadsheet when they graduate.

The advantages of spreadsheets are discussed by Cress (1989), Misovich and Biasca (1991), and Mortimer (1987), among others. Spreadsheets are easy to learn; one two-hour laboratory is sufficient to learn the basics. Spreadsheets remove much of the tedium from doing calculations and allow the professor to assign more meaningful problems. "What if?"

experiments are easy, and students can explore the effect of changing parameters, thereby gaining a feel for the magnitudes of parameters in problems. And in certain circumstances they can see what effects can be ignored. Spreadsheets are also easily adapted to discovery learning methods. Instead of being told, students can discover the effect of variable changes for themselves.

Spreadsheets are in many ways easier to use than programming. They are structured and encourage students to structure their calculations, even for hand calculations. A spreadsheet can easily show tabular solutions. It is easy to debug since syntax errors are shown immediately, and the instant display of numerical results makes it easier to spot obvious mistakes. Input and output are easy since any cell can be displayed or changed at any time. The inclusion of graphics capabilities means that students can easily prepare presentation-quality graphics and can search for trends visually instead of looking at a mass of numbers. In addition, spreadsheets are easily documented since each cell can be labeled.

Students invariably prefer spreadsheets to programming. In addition, it doesn't appear to make any difference if they learn programming or spreadsheets first (Genalo and Dewey, 1988). Students are also able to generalize the use of spreadsheets to other classes and will use them in follow-up courses.

Spreadsheets are not without problems. They are slow, large-scale branching is difficult, and it is difficult to use variable names (Mortimer, 1987). If students are unfamiliar with spreadsheets or do not use them for a significant period of time, their introduction along with engineering material may decrease the learning of material (Merino, 1989). This could well be due to oversaturation with new material. If spreadsheets are introduced early in a course and used throughout the course, this should not be a problem. For very large problems the use of spreadsheets becomes cumbersome if not impossible. For these problems discipline-specific programs are often preferable. For the solution of large systems of equations and for many numerical methods, equation-solving software is preferable.

In many engineering classes spreadsheets allow students to get to real engineering problems faster, and permit them to focus on thinking since the program does the routine calculations. We are strongly in favor of the integration of spreadsheets into the engineering curriculum at all levels.

Much of what has been said about spreadsheets also applies to equation-solving programs. There are many examples of the use of these programs in engineering education: FORMULA/ONE (Baxter, 1988), MathCAD (Head and Fry, 1989; LaBlanc, 1991; Rogers et al., 1989), MATLAB, and TK!Solver (Fowler, 1985; Harbach and Wiggins, 1985; Keedy, 1988b). With an equation solver the user lists equations and the program automatically generates a list of variables. The user gives values for the known variables and asks for a solution. The program then finds a direct solution or iterates to find a solution after the user supplies initial values.

Equation solvers perform the input and output routines for the user, including graphing routines, and they choose the algorithm, although the user may be able to override this choice. They are quicker to set up than programming. The user can do "what if?" calculations and can thus learn by discovery. The programs can be used for optimization by trial and error and thus are useful for design problems. The simple features of an equation solver can be learned in one or two laboratory sessions, but some of the more advanced features take considerably more time before the user becomes proficient.

The programs require that students know how to write the equations. However, they do not need to know how to solve the equations, and in the worst case the program can become a black box. Generally, the programs have little logic capability and cannot do branching. Each program has limitations; for instance, TK!Solver cannot solve differential equations either symbolically or numerically. MathCAD can solve differential equations numerically, but the manual is difficult to follow (Head and Fry, 1989). Unfortunately, equation-solving programs do not appear to be as generic as spreadsheets, and experience with one program does not necessarily translate to facility with another.

Since equation-solving packages have more power than spreadsheets, we recommend their use in upper-division engineering courses. Some coordination within a department is appropriate to ensure that professors are using the same package. Spreadsheets should be taught first since they are more generic, are more visual, are easier to learn, and are applicable to the problems taught in lower-division courses. Additionally, students who learn the power of spreadsheets are more likely to believe that the time invested in learning to use an equation solver will be well spent.

Symbolic algebra programs such as MAPLE, MACSYMA, Mathematica, Derive, and Theorist are starting to have an impact on the teaching of calculus throughout the United States and Canada (Tucker, 1990; Goodman, 1991). A significant number of math teachers think that these programs can remove some of the repetitive calculations and drudgery from learning calculus and that the net result will be better learning of the theory of calculus. However, very preliminary results suggest that it may be the better students who benefit from computer use and that the poorer students may actually do worse than in standard classes (Watkins, 1991). Although the majority of calculus students are still taught by traditional methods, the movement toward using symbolic algebra programs appears to be gaining momentum. This brings up several questions for engineering education. Should engineering professors be exploring the use of symbolic algebra programs in engineering education? What can symbolic algebra programs do in engineering education? How do we accommodate students who have been taught calculus with a symbolic algebra program and who want to continue to use the program?

A student who wants to use advanced software such as a symbolic algebra program should be encouraged to do so, but at the same time, he or she needs to realize that the program may not be available on tests. For relatively complicated problems, symbolic algebra programs appear to be useful in engineering analysis (Prudy, 1990) and engineering design (Lee and Heppler, 1990). Students using these programs were able to work much more complicated problems in greater depth than students who did not use the programs. The number of errors was reduced since the program did the routine manipulations and could check whether the solution was algebraically correct. Symbolic algebra programs can plot functional relationships. At least some of them can generate FORTRAN code from equations written in the symbolic language, which obviously saves time and reduces errors. However, symbolic algebra programs can make mistakes, do not mesh with each other, and demand large amounts of memory (Heppenheimer, 1991).

Unfortunately, a significant amount of time is required to become proficient with symbolic algebra programs (Prudy, 1990). Students who have used a program in a calculus class are already past this barrier. If other students are to use them, they will benefit from instruction

either in class or in an optional short course. This need for instruction brings up the old question of whether engineering professors should teach computer applications (or communication or whatever) instead of engineering. If a professor believes that there will be a net gain in the amount of engineering that students do in class, then the time spent learning a symbolic algebra program is well spent. Naturally, many engineering professors will also need to learn how to use the programs if they are to employ them in class.

Commercial application software such as CAD programs, ADAMS, ASPEN, NASTRAN, SPICE and pSPICE, and specialized simulation programs also have a place as tools for teaching engineering. These programs are extremely powerful, specialized, and realistic since they are written for practicing engineers. Unfortunately, they are usually not particularly user-friendly and are expensive to license. Commercial programs are often used in design classes (see Section 9.1) since they allow students to attack realistic problems. However, a university needs a large commitment to support computing (Eisley, 1989), and professors need to be committed to teaching students how to use the programs.

Specialized simulation programs written for a particular problem can be very useful since they allow students to "experiment" with otherwise inaccessible equipment (Squires et al., 1991) or to gain experience which would not normally be available until they are employed in industry (Kabel and Dwyer, 1989). Unfortunately, the commitment in time and money needed to produce large simulation programs robust enough for student use is huge. The only justification (other than a labor of love) for such a development is sharing programs throughout the country. Unfortunately, there are still barriers such as equipment incompatibility, a "not invented here" syndrome, and a lack of distribution networks which make such sharing difficult. A promising start for the disemination of specialized programs has been made with centers such as the NSF/IEEE Center for Computer Applications in Electromagnetic Education (Iskander, 1991).

Students using computer tools can suffer from the black box syndrome. As the program becomes more complex, it becomes increasingly likely that the student will not understand or perhaps even care what it is doing. When this occurs, the possibility of "garbage in, garbage out" becomes increasingly likely, and the student may not be able to detect errors. We believe that students should do simple hand calculations and then repeat the problem with a computer. This helps them understand what the computer is doing, gives them confidence, and shows them how the computer can save time. Whelchel (1991) professes the opposite view and states that technology has become too complicated for students to understand all the techniques; thus, he suggests trusting the software.

8.2.2. Computer-Aided Instruction

In computer-aided instruction (CAI) a computer is used to teach the material to the student. Thus, the computer becomes more than a calculational tool; it supplements or replaces the traditional forms of instruction. In the past CAI was hardware-limited, but at many schools this is no longer true. Software has now become the limiting step, and we will focus on what the software does and on the problems of software development. It is not possible here to

describe exactly what a well-written CAI program can do. Readers interested in exploring this teaching method will need to explore the capabilities of a well-written CAI program on their own.

Simons (1989) identifies three major modes for CAI. In the drill-and-practice mode a student is presented with a question or problem, the student responds, and the computer provides feedback on the response. This mode can serve as a supplement to traditional instruction. In many ways drill and practice is similar to textbook homework assignments followed by feedback from a TA or a grader. The advantages of a computer are that the feedback is instantaneous and private. And since the student is already using the computer, he or she is more likely to use computer tools to solve the problem. Although problem statements must be clear and unambiguous, the real art in developing a drill-and-practice program is writing the interactive feedback. The program should follow Figure 8-1f. A good program will help the student see where the error is and to avoid similar errors in the future. The feedback must be highly individualized for what a particular student does, and the environment must be highly interactive.

The disadvantages of drill and practice are similar to the disadvantages of other CAI modes. The student must get past the barrier of using a computer, which for weaker students may be a major impediment. Students can practice only when the computer is available, whereas a textbook can be used practically anywhere (e.g., while waiting at a doctor's office or sitting on a bus). Finally, developing good programs (discussed in detail later) is a major task.

The tutorial mode is a more complex, higher-level program than drill and practice. A tutorial contains instructional material and may be a replacement for traditional delivery methods such as lecturing and textbooks. In addition to content material, the tutorial should contain example problems and figures, include questions and problems, and have richer feedback than typical drill-and-practice program. Tutorials can guide a student to different lesson parts depending on his or her response. Since many students find a completely externally controlled tutorial frustrating, most tutorials now also allow the user to control movement through paging or a menu. The tutorial can guide the student through problem solving with prompts and then gradually reduce the number of prompts until he or she is solving difficult problems without help.

The third mode listed by Simons (1989) is simulation (discussed in Section 8.2.1 as a computer tool). We classify a simulation program as a tool if the program is written for general use. If it is explicitly written for instruction, we classify it as CAI. In engineering, the advantage of commercial simulation programs is that they have a potentially broader market, and more money will probably be spent on their development. In addition, these programs are clearly realistic since they are used by practicing engineers. A CAI simulation program is more likely to consider decision making explicitly and to have feedback if the student has difficulties. The simulation should have many options and decisions for the student so that he or she can practice the functions of an engineer.

Does CAI work? Yes, but only if the students use the programs. This is not a trivial statement since it not unusual for many students to refuse to use CAI programs (Canelos and Carney, 1986). Of course, this is not unique to computers. Some students refuse to read a textbook or attend a lecture, but the problem does appear to be worse with computers.

Do students who use CAI learn better than by traditional methods? It depends on the program. Many instances of improvement are reported (Canelos and Carney, 1986; Turner,

1988), but there have also been reports of no improvement when compared to traditional methods (Turner, 1988). If a computer program is simplistic and just does what a textbook can do (e.g., as shown in Figure 8-1e), then there is no gain in using CAI. If the computer makes a diagnosis of where the student's difficulties lie and refers the student to the appropriate information, then improvement is observed. Combining immediate feedback from a drill-and-practice program with diagnostics appears to produce increased learning. Complex simulation programs, particularly those involving dynamic operations, can utilize the full visual power of computers, and significant increases in learning can be observed (Turner, 1988). Thus, it is the quality of the message and not the use of the computer that is important.

One major difficulty with CAI is the amount of time required to author a CAI program. In his pessimistic article, Trollip (1987/88) states, "Whether or not assistance is sought, it comes as a nasty surprise to most who start in the field of instructional computing just how difficult it is to produce useful, good material, and how long it takes to do it." Most engineering professors do not have all the skills necessary to develop CAI programs, and a team must be assembled. The necessity of working with professionals outside engineering may be hard on an engineering professor's ego but is necessary to achieve a quality product (Onaral, 1990). Nelson et al. (1985) organized a twelve-member team to write CAI for a one-semester statics course, a multiyear project. This CAI was to support an existing textbook, and only twenty-five hours of CAI was being prepared. Much of the effort was expended to be sure that the CAI programs would give the user as much control as he or she normally has with a textbook! Of course, when completed, the CAI program will have the advantage of interaction and immediate diagnostic feedback. The use of new authoring languages such as the cT language can reduce the effort (Kuznetsov, 1990), but writing a CAI program remains a formidable undertaking.

This effort should be compared to writing an engineering textbook where a single author can do the job in about the same time period. Writing a textbook makes sense only if the book can be marketed and used by other professors. Then these professors and their students will benefit from the effort expended by the author. Fortunately, a highly sophisticated and effective marketing and sales system exists for textbooks. Although most textbook authors do not feel that their universities place enough value on writing textbooks, this activity is recognized for promotions and tenure.

The same arguments apply to CAI software, but unfortunately the marketing and sales system is not yet well developed for courseware. However, recent developments at both universities and commercial textbook publishers indicate that a marketing and sales system is being developed rapidly (Onaral, 1990). There are several additional obstacles to the wide distribution of CAI courseware:

1 Computer incompatibility. With the very rapid changes in hardware, software needs continual updating. This is difficult when the market is small.

2 Professorial indifference or in some cases hostility to CAI. Even if a professor wants to use CAI, there is the "not invented here" syndrome.

3 Cost. Not only must the very high development cost be recovered, but this has to be done from a smaller base than for a textbook. In addition, students will revolt if they have to pay for both a textbook and CAI software.

4 Rewards. Many universities give little if any credit toward promotion and tenure for the development of instructional software (Trollip, 1987/88). With the national publicity that the EDUCOM/NCRIPTAL software awards have received, this situation may be changing.

5 Identification with television. CAI is often identified with television and may be seen to encourage students to abandon books and traditional scholastic values (O'Neal and Vasu, 1991). This can feed professorial hostility.

Because of these problems, we think that the outlook for CAI is limited to courses that have large enrollments across the country. In engineering education, large enrollment classes include calculus, chemistry, physics, computer programming, and certain lower-division engineering classes. The engineering classes with large enrollments include circuits, thermodynamics, statics, dynamics, and fluids. Courseware for many of these courses has been developed under the $70 million Project Athena at MIT. Courseware is also available in electromagnetics (Iskander, 1991). The hope is that some of this courseware can be economically used at other institutions.

8.2.3. Interactive Laser Videodisc

Interactive laser videodisc (ILV) is a new technology which allows for the combination of a number of technologies. The capabilities of ILV are discussed by Flammer and Flammer (1986) and Meyer (1991). One side of a videodisc can store up to 54,000 still frames or twenty hours of audio combined with still frames. Each still frame can hold about 400 kilobytes; thus, the storage capacity for computer information is immense. Each side can store thirty minutes of live action. This means that live action is by far the most storage-intensive use of the disc. The videodisc has random access of any frame in two to three seconds. Access of adjacent frames is faster. Any frame, even from live action, can be frozen and looked at as long as desired. The access can be controlled manually or by computer. ILV systems can incorporate a number of media:

- Photographs and text material.
- Overhead transparencies.
- Slides.
- Motion pictures.
- Videotape.
- Computer text and graphics.

One major advantage of new ILV systems is that a full screen of computer text and/or graphics can be recorded directly onto a videodisc frame.

An intelligent videodisc coupled to a powerful computer has all the capabilities of CAI systems with the added availability of multimedia presentation (see Figure 8-1g). Thus, ILV adds a new technological capability to what can be done with CAI. Because of the ability to

record directly from a computer to the ILV frame, existing CAI programs can probably be converted to ILV without a huge investment of time and money.

With write-once discs and videodisc recorders the costs of producing laser videodiscs has plummeted. McInerney and Kyker (1987) produced their own discs for $3000 and $5000, which is probably the current absolute minimum. These costs do not include the cost of the authors' time. This is thus not an inexpensive technology, even when done as cheaply as possible. However, a single disc can probably hold an entire course so long as no live action is included. In addition, once the master disc has been made, additional discs are not very expensive. Because of the random access nature of the discs, updating them is relatively easy even though they are write-once. A number of frames can be left blank, and they can be written onto when the program is updated. The computer access code can be changed so that obsolete frames are no longer accessed and the new frames are.

What are the advantages of ILV? First, there is the huge storage capacity which might allow the storage of an entire course on one disc. Second, ILV consolidates a variety of media into a single package. The problem of switching from one medium to another is solved (Meyer and Zoltowski, 1989; Meyer, 1991); this is particularly useful if short segments from a variety of media are to be used. Third, this technology allows the developer to bring in any visuals that are desired. Since most people prefer to learn visually (see Section 15.2.2), ILV should be an effective learning method. Several uses for ILV in engineering education have been proposed or tried.

1 Remote locations. ILV is a video technology which can be used in the same way as video. This can be in either a tutored or an untutored environment. One advantage of ILV over video is that shipping costs are significantly lower since the whole course can be sent in one small package. ILV has been used for continuing education in composites (Gillespie, 1989).

2 Individual self-study and PSI courses. ILV combines CAI with a host of visuals and could serve in self-study courses. In a PSI course a computer can test and grade a student and keep track of what tests the student has taken as well as the student's progress.

3 Student tutorials. ILV can be used in the same way as CAI, but again with enhanced visual capabilities (Flammer and Flammer, 1986). The remote access capability of ILV makes it preferable to video since students can quickly find the one segment they want to use (Meyer, 1991).

4 In-class use. The consolidation capabilities of ILV allow an instructor to show multimedia without switching problems. Dynamic simulations from a computer can be shown in faster than real time because the final results of simulations can be shown.

5 Laboratory simulations. The combined computer simulation and visualization power of ILV allows the development of very realistic laboratory and plant simulations. Students can "experiment" with situations which would be too expensive or too dangerous in real life. A nuclear power plant simulation, for example, could show a melt-down situation if the operator makes too many mistakes.

6 Outreach programs. McInerney and Kyker (1987) made a disc for high school teachers to interest students in physics.

ILV has a variety of different applications which involve different capabilities of the equipment. If a professor has already developed a multimedia presentation, then conversion to ILV would be relatively simple and could be done for a few thousand dollars. If a CAI program has been developed, conversion to ILV would again not be too expensive. Costs become very high when development is started from a zero base; thus, our comments about CAI are appropriate for ILV. ILV development makes sense only if the resulting disc can be shared among a large number of users. This requires a distribution network for either on- or off-campus use. One added expense is the equipment on which the discs will be used after they have been prepared. This cost is higher than for either CAI or video. Gillespie (1989) gives a list for IBM equipment.

Since ILV is a very new technology, it is too early to tell what impact it will have on engineering education. Advances in Hypertext software have reduced the advantages ILV once had compared to CAI. Our best guess is that ILV will carve a unique but small niche where it is clearly the best delivery system.

8.3. AUDIOTUTORIAL METHOD

The audiotutorial (AT) method is an educational system which uses technology and instructors to satisfy a number of the learning principles outlined in Section 1.4. First developed in 1961 by Sam Postlethwait in the biology department at Purdue University (Postlethwait, 1980, 1984), the method has had a considerable impact on the teaching of biology (Creager and Murray, 1971). AT has evolved significantly since 1961, and many different variants are practiced. We will describe it as currently practiced in two biology courses at Purdue University.

The course is divided into modules which require one week to complete. It is an instructor-paced course, but during each week students may select when to go to the AT facility. The facility is open Monday through Friday and on Sunday evening. Students are given a detailed course syllabus and a description of how the course works. For each week's module the student receives:

- Clear objectives.
- A reading assignment in the textbook.
- A journal article to read.
- Supplemental notes and study questions.
- A schedule of extra credit activities.

When students go to the AT facility, they first sign in with a TA. They are then assigned a carrel which contains simple instructions as to the order in which to proceed through the assignment. Lectures have been recorded on audiotape, and the students listen to them. The lecturer frequently tells the student to turn the tape off and do activities such as answering

questions or working on problems. In addition, students are directed to pick up and examine various objects in the carrel. They then must answer questions about these objects. They are also directed to a few laboratory experimental stations to conduct simple experiments such as looking at samples through microscopes, and so forth. TAs move through the room to help students who are having difficulty. A few of the modules use videotapes when there is a major advantage to having video in addition to audio. Obviously, with a large number of carrels (forty-seven), providing audio recorders is cheaper than video equipment. When ready, the student can participate in graded activities.

1 Every day there are small group teach-about-biology (TAB) sessions during which students make a short presentation on an item (specimen, demonstration materials, experimental results, etc.) which was seen during the student's self-study. The students do not know ahead of time what the item will be. The student is to teach the other nine students in the group about this item, and the TA grades each presentation.

2 The student has two opportunities during the week to take a "C-level" quiz, and the highest score is recorded. Mastery is the goal but is not always achieved in these quizzes. Successful completion of the C-level quizzes gives the student a C in the course.

3 During the semester the student takes two "AB-level" tests which are given in large lecture halls for one hour.

4 The student can take an optional final during finals period.

5 Several laboratory sessions must be completed and written up during the course of the semester.

6 The student can earn extra points by attending a general assembly for a lecture, film, demonstration, and so forth, and then writing a summary about the session. The summary is written in the last twenty minutes of the period. Extra points can also be obtained by writing summaries of journal articles.

7 The student can obtain bonus points by taking an optional quiz or by doing optional dissections.

The points are added up at the end of the semester, and a straight 90-80-70-60 scale is used for grading. Approximately half the students enjoy the course very much, work hard, and receive A's or B's. Procrastination lowers the students' grades, and approximately one-quarter of them receive D's or F's.

This course requires some responsibility on the part of the students since they must set aside time to go in. The deadlines have proven to be critical to the success of this course since first-year students still need structure. Students are aware of their progress, and they know the grade they have earned at every point in the semester.

In an AT course the professor plans and modularizes the entire course. This requires a mastery of the content. The professor records the tapes and revises most of them every year, prepares the objectives, and writes the supplemental material. When the textbook changes, most of the supplemental material must be extensively revised. He or she writes quizzes and tests, supervises the grading, and must be a manager if a large number of TAs are employed.

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The professor arranges for the general assembly sessions, even giving a few lectures, and finally, sets the tone for the entire course.

This system has built in many of the learning principles discussed in Section 1.4. Students are forced to be active. There is frequent feedback, and students can ask for help whenever they need it. They must teach others in the TAB sessions. Since a straight grading scale is used, the class is not competitive. Students are encouraged to cooperate and help others. A variety of visuals are used, and the class is multimedia (audio, video, real objects, tutoring, presentations, etc.). The student can to a large extent control his or her pace through the material and is given time to practice. Clear learning objectives and material for learning these objectives are provided, and the student is guided through this material. The audio lectures structure the material for the student. Each student is challenged in the course, yet each student can be successful. Finally, Postlethwait was extremely enthusiastic and clearly expected that every student would do well.

Applications of the AT approach in engineering were reviewed by Lindenlaub (1974). The method has been used for entire courses normally considered "lecture" courses. Several laboratories have been taught as AT courses. In addition, the AT method has been used to supplement both regular and laboratory courses. Use of the AT method appears to have peaked, even though many of the principles could clearly be adapted to other technologies. The problem is cost. Compared to a lecture course with one professor lecturing to anywhere from 400 to 500 students with a handful of TAs for office hours and grading, the AT class is expensive. Not only is additional equipment necessary, but a room must also be dedicated to this one class and more TAs are needed. The students in an AT class on average put in more time on the class and learn more. Retention for other classes and for graduation is higher. Unfortunately, most universities do not factor student learning into their system of determining the economics of a class.

We have included the AT method in this chapter because it can serve as a model of how technology can be incorporated into a system which satisfies essentially all the learning principles.

8.4. CHAPTER COMMENTS

It is extremely difficult to give the flavor of teaching with a technology in a book using print as the medium. If you are interested in any of these techniques, obtain samples and be a student for an hour or two using the sample to learn a topic. These demonstrations will give you a feel for whether you want to proceed in exploring use of the technology.

This chapter was also somewhat difficult to write since we have not been personally involved in developing CAI, laser videodisc, or AT courses. We have read extensively and seen extended demonstrations of these methods, but this is not a substitute for the first-hand experience we have had with all the other teaching methods discussed in this book.

8.5. SUMMARY AND OBJECTIVES

After reading this chapter, you should be able to:

• Describe and discuss the advantages and disadvantages of the following teaching methods:
- • Live television.
- • Tutored videotape instruction.
- • Videotape feedback for students.
- • Computer-aided instruction.
- • Interactive laser videodisc.
- • Audiotutorial.

• Discuss the advantages and disadvantages of using generic software packages in an engineering course.

HOMEWORK

1 Pick one of the teaching methods listed in the first objective of Section 8.5. Visit a facility where this technique is in use and act as a student for one class period to experience the method.

2 For the teaching method chosen for problem 1, outline in detail how the method could be used either to teach or to supplement a specific engineering course.

3 Outline how you would use generic software in a specific engineering course. If appropriate, consider how the students would learn to use the software.

4 One of the arguments against extensive use of simulations in engineering education is that students will use the software as a black box and will not look at the output critically. Delineate this argument. Read Whelchel's (1991) paper and discuss his arguments. Then develop methods to prevent this from being a major problem.

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