Since Teaching Engineering was first published in 1993, the rate of change in instructional technologies has been extremely rapid. As a result, Chapter 8 was out-of-date a few years after publication. Of course, the same condition still holds—anything published in this second edition on educational technologies will also be out-of-date in a few years. In particular, MOOCs (Massively Open Online Courses) will either fade into a niche or will prove that they can have a major impact on higher education.

This chapter also focuses on the how-to of teaching, except that here technological means are used to supplement, enhance or deliver the instruction. Since they grew up as digital natives, it should be no surprise that in many ways students are ahead of their professors and want their professors to use more technology in courses. A large survey by the Educause Center for Analysis and Research (2013) asked which technologies students wanted their professors to use more of, the same amount, or less. The results in Table 8-1 show that the availability of lectures for later use is the number one item. (Authors’ Note: this item probably refers to lecture courses, not courses using other teaching methods.) Students wanted professors to integrate the use of their electronic computing devices in class with a preference for laptops over tablets or smartphones. In addition, students wanted professors to make more use of available tools such as course management systems, collaboration tools, and free internet content. Only E-portfolios came up negative, probably because of the workload.

Why don’t faculty include more technology in their teaching?
1. They do not believe that technology will improve learning.
2. They are unfamiliar with the technology.
3. They do not think they have time to implement technology.
4. They do not believe there are rewards for using instructional technology. Only 20.3% of professors at 4-year institutions agreed that “Faculty members are rewarded for their efforts to use instructional technology” was very descriptive of their institutions (Higher Educ. Research Institute, 2009).
5. They do not have funding for a specific technology such as tablets.
Hopefully, the combination of chapters 7 and 8 will eliminate the first reason and this chapter will help ease the burden of the second reason.

Delivery media that can replace or supplement live instruction include television, video, streaming video on the Internet, and interactive computer tutorials. These materials may be delivered through a virtual learning environment such as Blackboard or Moodle. We will draw a distinction between live (synchronous) television, which may be delivered on the Internet, and asynchronous delivery by CD, DVD, or downloading from the Internet—all of which will be lumped together as video. 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 and video have been used to deliver lectures to remote sites or at different times. Video is 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 8.3.1 and 8.3.2 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 8.7.3)

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, video, non-interactive 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.

Table 8-1. Technology that College Students Wish Professors Would Use (Educause Center for Analysis and Research, 2013)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Use More %</th>
<th>Use Same %</th>
<th>Use Less %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecture Capture (for later use or review)</td>
<td>71.5</td>
<td>17.9</td>
<td>10.6</td>
</tr>
<tr>
<td>Course/Learning Management system (Blackboard, Moodle)</td>
<td>62.0</td>
<td>24.5</td>
<td>13.5</td>
</tr>
<tr>
<td>Integrated use in class of students’ laptops</td>
<td>60.9</td>
<td>21.7</td>
<td>17.4</td>
</tr>
<tr>
<td>Online collaboration tools (e.g., Blackboard Collaborate, Google Docs)</td>
<td>59.7</td>
<td>25.0</td>
<td>15.2</td>
</tr>
<tr>
<td>Integrated use in class of students’ tablets</td>
<td>51.1</td>
<td>20.5</td>
<td>28.4</td>
</tr>
<tr>
<td>Use free content (e.g., Khan Academy, OpenCourseWare)</td>
<td>49.4</td>
<td>27.4</td>
<td>23.1</td>
</tr>
<tr>
<td>Integrated use in class of students’ smartphones</td>
<td>49.0</td>
<td>20.2</td>
<td>30.8</td>
</tr>
<tr>
<td>Simulations or educational games</td>
<td>48.6</td>
<td>26.2</td>
<td>25.2</td>
</tr>
<tr>
<td>E-books or e-textbooks</td>
<td>47.1</td>
<td>25.3</td>
<td>27.6</td>
</tr>
<tr>
<td>E-portfolios</td>
<td>24.5</td>
<td>25.6</td>
<td>49.9</td>
</tr>
</tbody>
</table>

Note: Responses “don’t know” and “not applicable” omitted in analysis.
Over the years, the introduction of new technology for education has generated initial high excitement followed by disillusionment, although most technologies eventually 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 non-technological 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 non-technological delivery, the combination of technological delivery medium and teaching method will probably not survive after the innovator has moved on to other activities.

### 8.1. SUMMARY AND OBJECTIVES

After reading this chapter, you should be able to:

1. Describe and discuss advantages and disadvantages of the following teaching methods:
   a. Live television.
   b. Tutored video instruction.
   c. Video feedback for students.
   d. Computer-aided instruction.
   e. Intelligent tutorial systems
2. Discuss advantages and disadvantages of using generic software packages in engineering.
3. Explain whether MOOCs will have a major impact on engineering education.
8.2. TELEVISION AND VIDEO

We will discuss television and video as delivery media for the education of engineering students (Section 8.2.1), describe a particular form of instruction with video called tutored video instruction (Section 8.2.2), discuss the steps the professor should take to improve video teaching (Section 8.2.3), and finally, consider the use of video as feedback for students (Section 8.2.4). Throughout the chapter, video includes streaming video on the internet, any other delivery system for the video (tapes, CD, DVD or new technology), and screencasts.

8.2.1. Instructional Delivery by Television, Video, and MOOCs

What can delivery of instruction by television or video do better than other means of delivering instruction? First, they 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, they 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. Fourth, they can be used as “electronic” field trips. Fifth, if some organization will pick up the expenses, the material can be used to deliver a Massively Online, Open Course (MOOC) that is free to the world. Of course, the examinations and credit for the MOOC are not free.

Distance education, or the use of television and/or 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. Both synchronous and asynchronous forms are used, although the applications are somewhat different. Most universities offering engineering courses have used distance education for graduate-level courses that allow practicing engineers to continue their education to a master’s degree with minimal disruption of their careers and of their family life. North Dakota State University has a large number of undergraduate engineering courses available on the internet. On a national scale, the first accredited virtual university, the National Technological University (NTU), United States, was founded in 1984 (Wikipedia, 2014). NTU collaborated with many universities that did not have their own distance education programs and presented a wide variety of courses from a number of universities and offered master’s degree programs in engineering. Over the years many of the collaborating universities developed their own distance education programs. In 2002 NTU was purchased by Sylvan Learning Systems (now Laureate Education, Inc.), folded into Walden University in 2004, NTU stopped accepting new students in 2011 and then shut down.

Live (synchronous) educational television in engineering usually involves a professor lecturing 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.

With synchronous operation 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. Some form of visual feedback is also very useful since it
is difficult to discuss equations or drawings with audio alone. Smartphones and the internet have essentially solved this problem. The major instructional difficulties with live synchronous television are the lack of contact between the students and the professor, the cost and difficulty in doing anything other than “straight” lecturing, and the schedule from the teaching site is imposed on all the receiving sites. If some sites are in different time zones scheduling can be awkward. Although synchronous operation has the advantage of possible interaction with the instructor, the vast majority of students prefer asynchronous viewing since they can watch the video when it is convenient and they can watch difficult parts multiple times.

The television delivery system must be of high quality. In the past this meant that a professional-quality studio had to be available. Although professional quality studios are clearly the best, it is feasible to make a reasonable quality video without professional-quality equipment. The downlinks from the satellite must also be of professional quality for live television. In short, live television courses are expensive. Because of the expense and because students prefer the flexibility of the asynchronous courses, the future is the internet. The quality of the professor’s presentation is also critical, and this is discussed in Section 8.2.3.

Television and video delivery 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 15.3.1). Since the majority of engineers are field-independent, this will be less of a problem in engineering than in other fields. Still, you need to create a sense of contact and to build rapport. Visits to the remote sites during the semester can help tremendously. Professors and/or tutors can also have phone office hours every week, although few students will 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.

Video excels at showing visuals; unfortunately, most engineering programs do not take advantage of this characteristic. 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 video requires some creativity on the part of the professor.

Person-to-person classes that are on video or streamed on the Internet offer additional flexibility for students. If a student cannot schedule the class, he or she can always watch the video 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 video of the live broadcast. In addition, he presented an oral report to the class on video. Since finals were scheduled separately, he was able to take the final with the rest of the class. Although not widely used, video 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.

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 as meas-
ured by test scores from either television, video or online and from more traditional courses (Bourne et al., 2005; Canelos and Mollo, 1986; Gibbons et al., 1977; Scidmore and Bernstein, 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. At first glance the “no significant differences” result appears to contradict Chapter 7 that shows students learn more with active learning. However, in order to obtain significantly large samples these studies pool a number of classes together. The amount of active learning in each class and in groups watching video together was not controlled for. Thus, there could have been more or less active learning on-campus as off-campus. We would expect, but do not have the data to prove, that students in a class or group watching the video that engaged in significant active learning would learn more than students in a straight lecture course or students watching the video alone.

How would you like to teach 10,000 or 100,000 students in a single course? Some professors have done this in Massively Open Online Courses (MOOCs). MOOCs are essentially distance education on the internet with no limitations on who watches and no charge for watching. Two different types of MOOCs have evolved (Wikipedia, 2013). George Siemens of Athabasca University and Stephen Downes of the Canadian National Research Council are given credit for offering in 2008 the first collaborative or c-MOOC in which all students could be involved in blog posts and threaded discussions. The MOOCs that have been in the news in the US are from major universities such as Stanford, which started the hysteria by drawing huge crowds in 2011 offerings of computer science courses. Stanford, Harvard, Princeton, Michigan, and other well-known institutions have joined start-up companies such as Udacity, Coursera, and edX to offer MOOCs. Many of these courses present the material with little assistance for the students.

Kolowich (2013) surveyed all 184 professors known to have taught a MOOC and received 103 responses (56%). The professors thought that MOOCs could reduce the cost of a college education (45% significantly and 41% marginally), but they were less optimistic about cost reductions at their school. Most (66%) did not believe that their home institution would grant credit to students who succeeded in their MOOC, but 79% thought MOOCs deserved their current hype. Most (81%) thought that teaching the MOOC had taken time away from other duties. Professors chose to teach a MOOC for altruism, to extend their reach, to become better known, to get on the ground floor of the next big thing, as a major challenge, and perhaps because they were bored. The professors who had completed a term reported an average of 2600 students per course and a 7.5% pass rate.

Some colleges will accept certain MOOC courses for credit, but doing assessment online is a major challenge to avoid MOOC becoming “Massively Open Online Cheating.” How do you really know who is taking the test? Regional testing centers may be used, but security is still a major concern. Although there is a charge for the assessment and for the credit, it is cheaper than tuition. However, for introductory courses typically offered during the first two years of college, such as Calculus I, there already are well-organized, inexpensive ways to earn credit ranging from testing out at the school to taking a CLEP examination (in December 2013 these cost $80 per exam, which is $20 to $26.67 per credit) (College Board, 2013). If the student doesn’t need the prestige of an elite university, the MOOC can provide the information needed to pass a credit examination.
Are MOOCs going to change the educational landscape? With the current pass rates, they look like a niche technology useful for mature, strongly motivated students. However, using a MOOC as the pre-class lecture in a flipped class (Section 7.2) has enormous potential and could be the disruptive technology that changes higher education significantly. The resulting blended instruction is discussed in the next section.

8.2.2. Tutored Video, Tutored Screencast Instruction, and Blended Instruction

The other system that has been used extensively for the delivery of classes to remote sites is tutored video instruction (TVI), which is illustrated in Figure 8-1d. Obviously, screencasts (Section 8.2.4) can be used instead of a video—in the remainder of this section “video” will be understood to include screencasts. TVI 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 either streamed to a computer or shipped to the remote sites. In any of these formats the students can watch the video at their convenience. 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. Note that this method includes a significant amount of active learning. 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 or instructor instead of with the professor. The Open University in the UK uses essentially this procedure to teach literally thousands of students in a single course (Petre et al., 1998). The Open University is very careful that the lectures are of the highest quality—the production is not a professor sitting down at a computer with a camera attached. The tutored groups can then act as a cooperative learning group (see Section 7.3.2) and will have the advantages of cooperative groups. Writing for the New York Times Magazine, Traub (2000) explored the potential for national providers of the video. The 25 most popular US college courses account for 50% of the total credit enrollment. Thus, a small number of academic performers working with a few providers and a large number of instructors who facilitate learning could provide half of the college credit in the US. Note that this procedure is NOT a Massively Online Open Course (MOOC), but a MOOC can serve as the lecture part of the course. It will be more effective than a MOOC because many students need the structure and help provided by the tutors. However, the system is more costly to run than a MOOC, but cheaper than on-campus courses. Instituted on a large scale, it is likely to be a disruptive technology in higher education.
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 video.
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 video instruction has also been used to advantage on campus (Gibbons et al., 1977; 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 benefit 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 videos. Once prepared, videos often continue to be used even though they may have become outdated. TVI can also be abused if the professor who produces the video 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 video. (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.

There is every reason to believe that screencasts or MOOCs can be substituted for the videos with no decrease in learning. The materials may also be delivered through a virtual learning environment such as Blackboard or Moodle. Then the blended combination of video or screencasts plus live active learning is essentially a flipped classroom (section 7.1), except there may be a different instructor. Fox (2013) briefly reported on an analog circuits course at San Jose State University that used a MOOC from MIT as the pre-class lecture. In class the
students worked on lab and design assignments with assistance from San Jose State instructors. The results were higher test scores and much higher passing rates compared to the previous lecture style course. Education is very good at making small changes and then claiming the wheel has been reinvented.

Limniou and Smith (2010) obtained some interesting results in their study of a blended class. The professors valued the virtual learning environment (Blackboard) as a method for delivering large amounts of supplemental materials, announcements, and assessments, and for collecting assignments because delivery and collection of this material freed up class time. The instructors’ idea of teaching was that they delivered the content and the students would manage their own learning. Most of the students believed that teaching should be more interactive and collaborative. They found the discussion board (ignored by the professors) and the assessment tool that allowed for rapid feedback from the tutors to be most useful. Faculty need to catch up with their students in the use of virtual learning environments.

When lecture was invented in the 12th century, the limiting cost of education was the cost of books; currently, the limiting cost is the cost of instructors (Hennessey, 2012). Universities help students learn both in and out of class, and they provide credentials (in engineering education there are also assessment, skill development, and socialization functions). MOOCs are very good at providing information, but usually not as good at helping students who need help learning, and the providing of credentials still needs work. A blended system that delivers content knowledge, practice and feedback through the Internet plus face-to-face interactions in tutorials could replace most of the large, common classes in engineering education. The assessment, skill development, socialization, and credentialing functions would be done in tutorial, while the content knowledge and some practice in applying the content would be done through the Internet.

What makes the Internet delivery-tutorial system a potentially disruptive technology? The system would replace a large number of highly educated, expensive craftspeople (professors) who currently combine all of the functions of engineering education with a very small number of production teams for the Internet systems and a large number of less highly educated, and hence less expensive, instructors who would conduct the face-to-face tutorials. The examinations required for credentialing would be done in the tutorials, but common examinations written by the production teams could be used. Since they no longer develop content and probably would not be involved in research, instructors could handle a large number of tutorial sections. Community colleges and private institutions are likely to find that providing instructors and tutorial classes fits well with their missions. Prestigious universities would probably continue to be popular with students and would use the Internet delivery-tutorial system sparingly on campus. Less prestigious universities are likely to have significant drops in enrollment.

An even more disruptive scenario would marry a MOOC with an Intelligent Tutorial System (ITS) (see Section 8.7). The ITS would replace the face-to-face tutorials, and only a few tutors would need to be on call for situations when students had difficulties not addressed by the ITS.

Will one of these disruptive scenarios occur? Agriculture and industry have both seen the replacement of many workers by technology (Wasfy, Wasfy, Mahfouz, and Peters, 2013). We expect that eventually higher education will also use technology to replace teachers; however, the technology could be different from current technology. Thus, the question is not if this change will occur, but when and how quickly. One of Hennessey’s (2012, last slide) closing comments is “Be the disrupter; not the disrupted.”
8.2.3. 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. However, even great production facilities cannot compensate for poor instruction. The following hints will help ensure a good video:

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 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.
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. **Watch the video for feedback.** If necessary, adjust your teaching style. If the video will be reused, edit or reshoot unsatisfactory portions. Prepare a practice video 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 video 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 video and the written materials available online unless they are copyrighted and permission has not been obtained to use them.** Copyrighted materials can be made available at the library or learning center.

8.2.4. Screencasts and Video as Information Resources

Video and screencasts can provide information to prepare students for lab or a flipped (blended) class (see Section 7.2), or as a supplement while working on assignments. Although they obviously overlap with distance education applications, in this section we address screencasts and videos made by the professor without the services of a professional studio. Obviously, a professional studio could also be used.
Videos of lectures made in class one semester can be used the next semester to prepare students for class sessions devoted to problem solving, creative design, debates and other activities. The videos need some editing to shorten them and to remove items that are not pertinent for the current semester. Major advantages of videos and screencasts are that students can watch them on their own time and they can watch confusing parts multiple times.

Screencasts have been in the news lately based on the success of the Kahn Academy (Kahn, 2013). Although the Kahn Academy has focused mainly on elementary and middle school content, screencasts can easily be applied for university courses. Screencasts of lecture slides with the professor explaining the slides can substitute for videos. If a camera is available for the computer, a head shot of the professor lecturing is an option that can be included in the lower corner of the screen. It is important to have good materials and good sound. Use a quality microphone and check the sound levels on the resulting screencasts. One semester my microphone did not operate well, the description of the slides was hard to hear, and the flipped class had difficulties. The talking head is optional.

Screencasts for a flipped class should be short, preferably 15 minutes, but certainly no longer than 30 minutes. Some type of check that students watch the videos or screencasts will be necessary if the flipped active learning class is to be successful (Section 7.2). If extensive problem solving details cannot be included in 30 minutes, make a supplemental screencast that shows examples of solving problems.

Why not tell the students to read a good textbook before the flipped class? First, many students will not read carefully if they read at all, and many students avoid buying textbooks because of the expense. Second, the students think you are teaching with screencasts that you made. Since you are teaching, they should study. Textbooks do not have the same effect. Third, most students learn and remember more from a combination of voice and slides than from either one alone (see Chapter 15).

An alternate use of screencasts is as a supplemental aid to problem solving (Falconer et al., 2009, 2012; Lemley and Jassemnejad, 2012). The screencasts (or pause-play-rewind technology) show steps in the problem solution for examples while the professor explains the solution. The screencasts can either be made on a PC with PowerPoint slides or on a tablet PC with a hand-written solution. Falconer et al. (2012) present a recipe for making screencasts. Many students want to see as many examples as possible—perhaps in the hope that one will be quite close to a homework problem. Falconer et al. (2012) present data showing that many students use the screencasts, students who use the screencasts on average earn higher grades on tests, and these students believe the screencasts are very helpful. These results agree with those obtained in a materials engineering course (Green et al., 2012). Screencasts can also be used as an alternate to posting solutions of homework or test problems. For chemical engineering topics, screencasts are available for both students and professors at www.learncheme.com.

Video can conveniently 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 a video, CD, or URL. We have used this procedure with good results even though the videos were homemade. Since the students were very motivated to learn from the video and since they watched it in groups of three, the homemade character of the video was not a problem. Videos 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. Once produced, the video 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 videos of biomedical equipment and techniques can easily be shown to classes which might not otherwise be able to see the procedures. Squires et al. (1991) used company-produced videos of plant tours to show students a chemical plant without the time and expense of a field trip. The advantage of involving companies is that once they decide to support the video they pay for a professional company to produce it. These videos can then be used at many schools to justify the production costs. Other applications of video supplements to other teaching methods await the ingenuity and energy of individual professors.

8.2.5. Video Feedback for Students’ Oral Presentations

Video feedback is the premier technology for showing students how others see them. If oral communication or interpersonal teamwork is required, video feedback to students is invaluable. Fortunately, such use can be relatively inexpensive. Many students are afraid to appear before a camera, and videotaping in a normal classroom is less threatening. Although it is convenient to have a TA or undergraduate assistant serve as camera operator, this is not absolutely necessary. The camera can be pre-focused on the tripod and then be turned on before the students start.

Procedures for oral reports are discussed by Wankat et al. (1977). First, get the students accustomed to the camera 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. These visuals will probably not show up on the video, but this is unimportant since the purpose is feedback, not communication to others. Have the class ask questions and continue to record the speaker while he or she responds.

No one likes the sound of their voice on video, and many people do not like the way they appear on camera. Since the student is likely to be embarrassed, show the video privately (COSEPUP, 1997). Most students will be very severe critics of their presentation when they see the video. If a student becomes upset while watching the video, 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 thirty years of recording 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; 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 feared. For every student appalled at seeing himself or herself, many more enjoy watching themselves.

Additionally, recording oral reports greatly improves the instructor’s ability to give feedback. While watching the video, 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 videos 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, videos can also be very helpful for interpersonal training. A camera is very effective 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, videos 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 record 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 result for feedback. Stop the video at appropriate places for a discussion of what has happened. If one member of the group is obstructive, it is probably appropriate to show the video 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.

8.3. COMPUTERS IN ENGINEERING EDUCATION

There have been hand calculator and computer revolutions in engineering education. The hand calculator had a major impact rapidly by displacing slide rules and allowing students to solve realistic problems that were impossible with slide rules under the time constraints of a normal test. The computer revolution was slower and less far-reaching than many prophets predicted. Computers and calculators have greatly increased the ability of students (and practicing engineers) to perform calculations, so 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). So far, significant adoption of computers for the delivery of instruction has occurred only for streaming video and screencasts.

Computer learning tools (e.g., software, courseware, mobile devices) “are nearly ubiquitous in engineering education” (McMartin et al., 2014, p. 12). The commonly used generic computer calculation tools are spreadsheets, equation solvers, and symbolic algebra and calculus programs. Simulation programs (Section 8.5) tend to be much less generic but will be discussed with the other tools. Youtube and wikis are explored in Section 8.6. In Section 8.7 we will discuss computer-aided instruction, which uses a computer to deliver instruction. Table 8-1 showed that students want more integration of their computing tools in class.

Before any computer application is adopted, 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 poorer performance (Whitney and Urquhart, 1990).

### 8.4. Computer Calculation Tools

Engineering professors have discovered that students prefer to use generic software such as spreadsheets and equation solvers instead of programming. 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 calculator 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 calculators 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 them how to use the software in the first year 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 (1988) 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% 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.

As long as a spreadsheet has appropriate graphing and scientific function features and is fast enough, the choice of spreadsheet is almost immaterial; however, Excel® is certainly most common. 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. Applications of spreadsheets in engineering courses have exploded and they have been used in all engineering disciplines. Chapra and Canale (1988) show how spreadsheets can be used to implement a variety of numerical methods. Jordan (2012) wrote an Excel manual that is useful for both professors and students. The advantages of spreadsheets are discussed by Jordan (2012) and many 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?” computational 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. 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. Since spreadsheets are also extensively used in industry, their use is also realistic. We are strongly in favor of integrating spreadsheets into the engineering curriculum at all levels.

Spreadsheets, however, are slow, large-scale branching is difficult, and it is difficult to use variable names. 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. This could well be due to oversaturation with new material. If spreadsheets are introduced early 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.

Much of what has been said about spreadsheets also applies to equation-solving programs such as Mathematica, MathCAD, MATLAB, and TK solver. 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. 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.

8.5. SIMULATIONS AND GAMES

This section covers computer simulation and educational computer games. Simulations without computers are discussed in Section 7.6.4.

In our opinion commercial application software such as ADAMS, ASPEN, NASTRAN, SPICE and pSPICE, and specialized simulation programs must be used in engineering education because practicing engineers use simulations. We classify a simulation program as a computer tool if the program is written for general use. If it is explicitly written for instruction, we classify it as computer-aided instruction (CAI). Programs originally written for research purposes are also used in engineering courses (Magana et al., 2012). 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.

Simulation can easily be an active learning method in a discovery mode or asking “what if” questions. These programs are extremely powerful, specialized, and realistic since they are written for practicing engineers. But, they are usually not particularly user-friendly, often have a bewildering variety of features, and may be expensive to license. Commercial programs are often used in design classes (see Section 9.2) since they allow students to attack realistic problems. Although universities need a large commitment to support computing, most universities have decided that this commitment is necessary. Unfortunately, professors also need to be committed to using the simulators in class and must be willing to teach students how to use the programs if necessary. If the students are already proficient in the program, simulators can easily be included as part of the assignments. If the students have not been trained in the program, they must be trained as part of the course (Nijdam, 2013; Wankat, 2002). This is probably easiest to do in computer laboratories with every student using a computer.

Does use of an engineering simulation program increase student learning? Since simulators are used extensively in industry, they are realistic. Simulators are also a method of active learn-
ing. Both of these attributes would tend to increase student learning. Controlled experiments by Davidovitch et al. (2006) found increased learning and retention when students used the Project Management Trainer simulator. In addition, the use of the built-in learning history, which allowed students to look at past decisions and their consequences, increased student learning and helped in the transfer of knowledge and skills to other contexts. Kollöffel and de Jong (2013, pp. 317–318) found increased conceptual understanding when students were required “to make predictions, design experiments, analyze and interpret the collected data, and formulate answers to their research questions” using a simulator (described as a virtual lab) written specifically to mimic the physical laboratory equipment. Use of both the virtual lab and a real lab was recommended. Although student resistance is common when students are required to use new active learning technology (Koretsky and Brooks, 2012), we have observed very little student resistance from students to the use of commercial software. After requiring use of the software for over 15 years, students accept it as part of the normal program.

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). Real effects such as measurement errors and stiction can be programmed into simulations (Goodwin et al., 2011), but these “virtual laboratories” should not be confused with in-person or remote labs that use real equipment. The virtual labs should only be used as a supplement. Unfortunately, the commitment in time and money needed to produce large simulation programs robust enough for student use is huge. Unless significant amounts of grant money are available, the programs would have to be sold to recover the development costs. However, there are still barriers such as equipment incompatibility, a “not invented here” syndrome, and the lack of proven markets which make program development difficult. Intelligent tutorial systems (ITS, Section 8.7), which also require extensive development, have developed a market. The ITS systems had significant grant funding for early development and focused on courses with very large enrollment.

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 need to understand what happens when they do calculations and obtain an unexpected result. Doing simple hand calculations and then repeating the problem with a computer helps them understand what the computer is doing, gives them confidence, and shows them how the computer can save time. Whelchel (1991) disagrees and states that technology has become too complicated for students to understand all the techniques; thus, he suggests trusting the software.

Educational games are a form of simulation except games have a goal which is usually to obtain the highest score or beat an opponent. Video games can satisfy many of the requirements necessary for learning such as increased time on task and can result in more learning than occurs in lectures; however, these results are not automatic (Mayo, 2007; Whitton, 2010; Whitton and Moseley, 2012). Games are “active learning environments, which have the potential to teach higher level skills such as analysis, application and evaluation” (Whitton, 2009, p. 3).
Educational games are designed to be constructivist—that is, players learn by doing and constructing their own knowledge structure (see Section 15.2). To be useful in higher education, educational games will have to overcome a certain amount of initial negative reactions. Assessment and proof of learning of higher order skills will be required for acceptance of educational games. In addition, the following items are important in adopting an educational game (Whitton, 2010; Whitton and Moseley, 2012):

1. Just because an educational module is packaged as a game, does not mean students will be motivated to use it. Stating that games are motivational is not necessarily true and over-simplifies adult motivation for learning.
2. The use of games in education should be driven by pedagogical needs. Will the game help the student learn?
3. The game needs to be integrated into the curriculum.
4. Not all students will love games. Will there be alternatives for these students or will the game adjust to different learning styles?
5. The technology available must be able to support the game, and the game must be affordable.

Although cooperative learning is an extremely effective learning strategy, competitions are also effective motivators particularly when evenly matched cooperative teams compete. An early software game was the “software hut game” which asked student groups to develop software and improve another team’s software (Horning and Wortman, 1977). Sindre et al. (2009) found that a game resulted in the same amount of learning in a computers fundamental course as doing a paper and pencil worksheet; however, significantly more students would do the game than the worksheet.

Lu et al. (2010) used the computer game Tetris to teach computer engineering students object oriented programming with Java and C++. The semester-long project was divided into four parts: generating Tetris pieces with four to seven squares each, developing a one-player game, developing a two-player game, and a competition. Lu et al. (2010, p. 6) “found that through this four stage group programming assignment, many students demonstrated strong capability in writing network enabled programs, designing effective and efficient algorithms for artificial intelligence and team collaboration.” We can conclude that constructing a computer game is a natural use of games in computer programming courses. If the game ties into the students’ competitiveness and they believe they have the chance to win, students will work extremely hard (Wankat, 2005).

A relatively obvious, but untapped, use of games in engineering education is for helping students satisfy ABET professional criteria. The US military uses video games to teach language and culture (Lytal, 2014). A similar video game would help students satisfy ABET criterion 3h (“the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.”). Games should also be able to help students satisfy ABET criteria 3d (“an ability to function on multidisciplinary teams) and 3e (“an understanding of professional and ethical responsibility”).

Unfortunately, the use of games in other engineering areas is not as obvious. Bernhardt et al. (2010) used the game Shortfall, which was designed to help engineering students understand the tradeoffs among economic, environmental, and technical issues. The game is structured around supply-chain issues in the automotive industry. Originally developed as a board game, Shortfall has been converted to computer use. It was clear from the discussion of the results that even after
many years of development the game was still not ready to be used on a large scale. The comments in section 8.7 about time to produce a good CAI or ITS product and the need for an instructional team also apply to instructional games. Instructional games have the added disadvantage that most students are accustomed to the very high production standards of commercial games and may be demotivated by efforts of lower quality. However, there is light at the end of the tunnel and tools to make game production easier are available at the Whitton and Moseley (2012) website.

Mayer et al. (2013) argue that in many cases students will accept a lower level of technical sophistication if it is adequate for the purpose. They compared 14 games at different universities all constructed with the same two-dimensional game-based learning environment that is useful for online role playing, but not for operator training. Their conclusions were that the quality of the facilitator/trainer and the degree to which the game experiences were translated back to the learning objectives determined the students’ satisfaction with their learning.

### 8.6. YOUTUBE AND WIKIS

This section discusses use of videos from web locations such as YouTube in engineering courses and the somewhat surprising advantages of using wikis. Texting is discussed in Section 10.3.1 These tools plus many more such as blogging, Facebook, Google docs, Twitter, and web conferencing are being used by professors for communication, collaboration, showing videos, increasing information literacy, and other educational activities (Ferris and Wilder, 2013).

Since videos are excellent for showing action, they can provide visual impact and supplement textbooks, simulations and lectures. For example, the US Chemical Safety Board has a number of free safety videos available that dramatically show the results of accidents (http://www.csb.gov/videos/). These videos are obviously of interest to chemical engineers, but they are also of interest to materials engineers since corrosion is often the cause of the failure (e.g., Chevron Richmond Refinery Fire Animation; NDK Crystal Inc. Explosion with Offsite Fatality), food engineering and mechanical engineering (Inferno: Dust Explosion at Imperial Sugar), petroleum engineering and mechanical engineering (Partridge Raleigh Oilfield Explosion and Fire), and many others.

YouTube is a convenient site to find and store videos that can be shown in lecture or that students can download at leisure. Hrenya (2011) challenged students to determine the outcome of an experiment using a mechanical energy balance. Obviously, the experiment can be run as a demonstration; however, this requires equipment that may not be available and there is set up and take down time required. As an alternative, a video of the experiment is available on YouTube (Hrenya, 2011).

A second use of YouTube is to involve the students in active learning with YouTube videos. Liberatore (2010) had students find short YouTube videos that illustrate course material and showed the videos once per week. Since the students selected the topic and the YouTube video, there was considerable opportunity for creativity. Merrick (2010) used YouTube videos to introduce puzzles in an introductory computer science course. Hrenya (2011) had the students report on answers for puzzling fluids questions—they were encouraged, but not required to develop their own YouTube videos.

A third use of YouTube videos is to have student groups produce their own video as a course project. Examples of chemical reaction YouTube videos from the University of
A wiki is a collection of shared, linked documents that can be easily edited by users with a browser. The best known wiki is Wikipedia, the free online encyclopedia that can be edited by almost anyone who signs in—almost anyone because some articles have been the subject of vandalism. Many professors are doubtful about letting students use Wikipedia as a source. However, in a study reported in Nature, Wikipedia was almost as accurate as the online Encyclopedia Britannica (Giles, 2005). We let our students use Wikipedia—they will whether we let them or not—but Wikipedia cannot be the only reference. Letting the students use Wikipedia also provides an opportunity to discuss the accuracy of data on the Internet. Another application of Wikipedia useful as a course project is to have student teams write an article following Wikipedia conventions (Britt, 2013).

Wikis also provide another avenue for student-student and student-professor interaction (Hadley and Debelak, 2009). Since wikis can be contributed to and edited like a word processor, no knowledge of html is required. Wikis are particularly useful for extensive projects such as a semester-long design project because wikis keep a history of revisions. The history allows students to return to an earlier version if the revision process has strayed. The students found wikis to be very useful as a central location to store files and the immediate availability of the wiki made it useful for scheduling meetings. However, students felt they learned more working on their own wiki pages than reading other’s pages, and students were definitely uncomfortable evaluating other students’ work (Tsai et al., 2011).

Professors can use the wiki history to keep track of the progress of student groups and make immediate suggestions or corrections. Students reported that the wiki greatly increased the amount of assistance they received from the TA and the professor during their design project (Hadley and Debelak, 2009). The wiki history also allows the professor to check on the contributions of individual members in the group, which provides a way to check on peer reports of loafing. Wikis also provide a very convenient method to have students peer review the reports of other student groups (Heldt, 2012).

Ganago et al. (2010) tried using a website and a wiki to support TAs in a very large laboratory course. The TAs found the website to be a useful place to find information. However, since the TAs did not contribute much content to the wiki, it was not a useful method for passing information from one TA to another. When wikis are used with students, there has to be a small reward to encourage participation. Getting students to engage in blogs is similar—there has to be some tangible reward for the students. Krousgrill and Rhoades (2014) found that approximately half of the class would blog about how to solve the homework. The reward was a better grade on homework since the bloggers normally got even very difficult problems correct after considerable discussion. Since the blog resulted in a significant amount of reflective thinking, bloggers learned more.

8.7. COMPUTER-AIDED INSTRUCTION AND INTELLIGENT TUTORIAL SYSTEMS

In computer-aided instruction (CAI) a computer is used to teach the material to the student: it supplements or replaces the traditional forms of instruction. In the past CAI was hardware-
limited. Software has now become the limiting step, and we will focus on what the software does and on the problems of software development. Readers interested in exploring this teaching method will need to explore the capabilities of a well-written CAI program on their own (e.g., see Carnegie Learning, 2013).

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 must follow Figures 1e and 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. With the advent of extremely portable machines, the requirement that a computer with the software installed had to be available is much less of a problem than it used to be. 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 students to different lesson parts depending on their responses. 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 students are solving difficult problems without help.

The third mode listed by Simons (1989) is simulation (discussed in Section 8.5). A CAI simulation program is more likely than a general simulation package 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. Students often refuse to use CAI programs (Roskowski et al, 2002). 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 (Graesser et al., 2005; Kadiyala and Crynes, 2000; 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., 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 immediately to
text that includes the appropriate information, improvement is observed.

Starting in the 1970s, more sophisticated Intelligent Tutorial Systems (ITS) were developed
that constructed a model of the student’s learning approach and then provided individualized
instruction to correct errors (Wenger, 1987). The goal was to approach the approximately two-
sigma improvement in learning that commonly occurs with trained human tutors (see Section
10.3; “Sigma” is a commonly used term for the standard deviation. Improvements in sigma are
based on a normal distribution. An improvement of two sigma means an average student would
score in the top 2% of the class.). The early ITS programs were more effective than other CAI
programs, but students would stop using the program when they became bored or frustrated.
The designers had forgotten to study what skilled human tutors do (see Section 10.2). After
experienced human tutors were studied and dialogue was added, significant increases in student
learning resulted (Nkambou et al., 2010). A typical ITS can produce about 1 sigma increase
and in some cases with natural language dialogue built into the tutor up to 1.5 sigma (Graesser,
2005). The commercial Carnegie Learning ITS algebra tutor reports 15–25% improvement in
basic skills and 50–100% improvement in problem solving (PACT, 2005; Carnegie Learning,
2013). Perhaps overly optimistic predictions are that ITS systems will be able to equal or exceed
the improvements observed with one-on-one tutoring (Wasfy et al., 2013).

Paul Steif at CMU and Anna Dollár at Miami University, Ohio have developed a sophisti-
cated ITS-spreadsheet system for teaching statics that includes assessments—an online, interac-
tive textbook (Dollár and Steif, 2006, 2008). Steif and Dollár (2009) found statistically significant
learning gains from use of the courseware by approximately three-quarters of the students. The
book can be accessed free at http://engineering-education.com/OLL.php. The software has been
used as the lecture material in a flipped course (Grose, 2012) (see Section 7.2).

One major difficulty with CAI and ITS is the amount of time required to author a CAI or
ITS program. Trollip (1987/88) states, pessimistically, “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 engi-
neering professors do not have all the skills necessary to develop CAI programs, and a team
must be assembled. Nelson et al. (1985) organized a twelve-member team to write CAI for a
one-semester statics course, a multiyear project. This CAI was intended to support an existing
textbook, and only twenty-five hours of CAI were 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 (e.g.,
the Cognitive Tutor Authoring Tools developed by PACT, http://ctat.pact.cs.cmu.edu/) can
reduce the effort, but writing a CAI program remains a formidable undertaking.

The effort to develop an ITS product can be compared to writing an engineering textbook
where a single author can do the job in the same or less time. Economically, writing a text-
book 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 text-
books, this activity is recognized for promotions and tenure.
The same arguments apply to CAI and ITS software, and the marketing and sales system is still being developed for courseware; however, see the Carnegie Learning (2013) advertising. There are several additional obstacles to the wide distribution of CAI and ITS courseware:

1. **Computer incompatibility.** With every change in hardware or operating system, software needs to be updated. This is difficult when the market is small.

2. **Professorial indifference or in some cases hostility to CAI and ITS.** Even if a professor wants to use CAI or ITS, 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 or ITS software.

4. **Rewards.** Many universities give little if any credit toward promotion and tenure for the development of instructional software (Trollip, 1987/88).

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 and with current high development costs, we think that the outlook for CAI and ITS is limited to large enrollment courses. In engineering 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. On the other hand, Wasfy et al. (2013) argue that ITS, perhaps in combination with MOOCs, will become a disruptive technology that will increase student learning with significantly lower costs resulting in widespread loss of teaching positions.

### 8.8. 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. The predictions (see the last paragraphs in Sections 8.2.2 and 8.7) that a disruptive technology will drastically affect higher education should be a strong motivator to pay attention to these methods.

This chapter was also somewhat difficult to write since we have not been personally involved in developing CAI, or ITS. 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 most of the other teaching methods discussed in this book.

Some examples of teaching with technology fit better in other chapters. Efficient use of computers was retained in Section 2.4.2; because clickers are used almost exclusively in lecture courses, clickers are covered in Section 6.7.4, flipped courses were included in Section 7.2; remote labs fit better in the chapter on labs (Section 9.3.5); programs which check for plagiarism fit well into Section 12.2.1 on preventing cheating; Section 16.5 is a natural place to discuss use of video to improve teaching.
HOMEWORK

1. Pick one of the teaching methods listed in the first objective of Section 8.1. Visit a facility or web page 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. Explain this argument. Develop methods to prevent this from being a major problem.

REFERENCES


