CHAPTER 7

NONTECHNOLOGICAL ALTERNATIVES TO LECTURE

The lecture method can be particularly effective if the goal is to have students learn objectives in the three lowest levels of Bloom's taxonomy, but it is not the best method for higher level cognitive objectives such as analysis, synthesis, evaluation, problem solving, and critical thinking. In Chapter 8 alternatives to the lecture which use technology such as TV, computers, and laser videodiscs are discussed. Chapter 9 covers methods commonly used for teaching design and laboratory courses, and Chapter 10 considers one-to-one aspects of teaching. In this chapter we look at nontechnological alternatives to lectures.

The discussion method of teaching, fairly common in the humanities, is seldom used in engineering; however, it can be a very useful supplement in lecture classes. In cooperative groups most of the learning occurs with students working together in small groups. This method has been used for the entire course or as a supplement in lecture classes. A variety of other methods such as panels or debates can be used to spark student interest and encourage student involvement. Mastery learning requires that students reach a particular level of mastery on tests but gives them repeated chances to do so. The Keller plan and the personalized system of instruction method (PSI) employ mastery learning in a format that allows a student to control the rate of progress through the course. In individual study a student studies alone or with occasional tutorial help to satisfy certain objectives. Field trips can be used as part of any course to help meet the course goals. Evidence will be presented that for certain objectives these methods can be more effective than lectures.

7.1 DISCUSSION

Perhaps because discussion is a commonly used teaching method in their disciplines, social scientists and professors of education have studied it extensively (Cashin and McKnight,

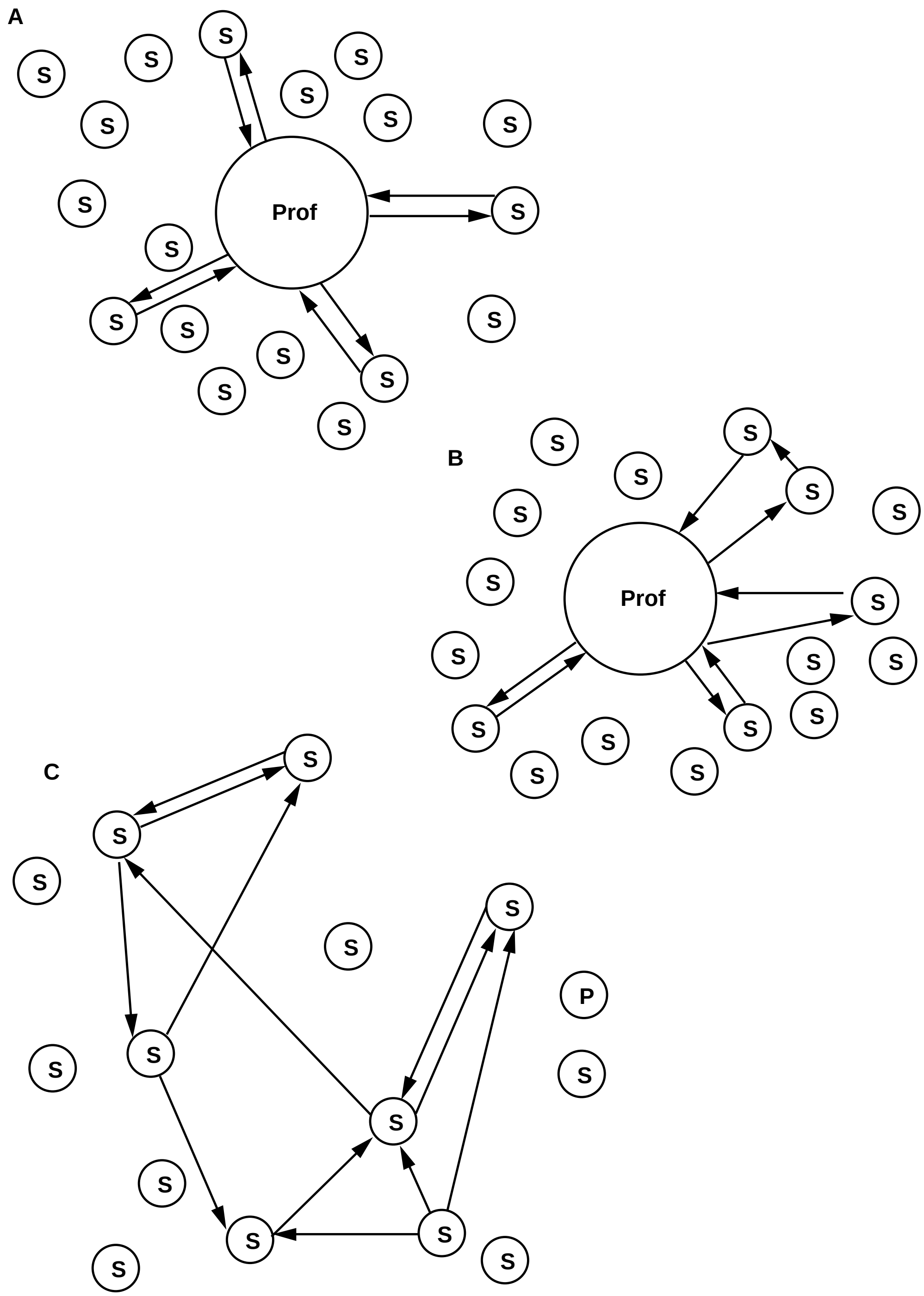

FIGURE 7-1 INTERACTION STYLES. A. Questions. B. Instructor-lead discussions. C. Student-centered Discussions.

1986; Davis et al., 1977; Eble, 1988; Lowman, 1985; McKeachie, 1986). There is ample scientific evidence cited in these sources which shows that discussion is not an efficient method for transmitting facts and data, particularly when compared to lectures. For teaching the three lowest levels of Bloom's taxonomy, discussion and lecture students do equally well on tests, and the lecture students learn the material more quickly. However, discussion and questioning are superior to lecture in teaching analysis, synthesis, evaluation, problem solving, and critical thinking. There is also some evidence that students remember material they learn through discussion or questions longer. Therefore, discussion should be considered as a teaching method in engineering when the professor wants to work on these higher-order processes. Since many of the benefits of discussion can be obtained with rather short periods, the engineering professor does not have to change her or his entire teaching method.

In order to participate in an intelligent discussion, students have to know something about the topic. Thus, we like to use discussion as a break in a class which is basically a lecture class. Another use of discussion is the cooperative group learning method which is included in both this section and in Section 7.2.

Discussions and questions (see Section 6.4) aim to involve students in the material and to interact with others. The main difference between question sessions and discussion is in the style of interaction. The interaction in a question period is clearly between the professor and individual students (see Figure 7-1a). The professor is definitely in charge, whether asking or answering questions. This is not an exchange among equals. In the student-centered discussion shown schematically in Figure 7-1c, all participants are roughly equal. The professor may participate but does not lead, and in small "buzz" groups the professor is often working with another group. The instructor-led discussion shown in Figure 7-1b is intermediate between these two methods. The instructor is clearly in charge but encourages significant interaction between students.

The instructor's control is greatest in the question format and least in student-centered discussions, so there is less that can go wrong in the question format and this procedure appears to be more efficient. However, student gains in problem solving and critical thinking are highest in well-functioning student-centered discussions (McKeachie, 1986). In addition, student changes in attitude are highest in student-centered groups.

7.1.1. Advantages and Disadvantages of Discussion

All teaching methods have advantages and disadvantages. The professor needs to select a method which is appropriate for the material to be taught, fits the students to be taught, and fits the professor's style. Since the competition to discussion is often the lecture method, the advantages and disadvantages of discussion will be compared to those of lecturing. Among the advantages of discussion are the following:

1 Students learn how to do analysis, synthesis, evaluation, problem solving, and critical thinking better.

2 There appears to be better retention of material.

3 Discussion is an effective method for changing student attitudes (affective objectives).

4 Intellectual development (see Section 14.2) is greater.

5 Students are more active and become more involved.

6 In engineering, discussion is a novel method which gains the students' attention. It also breaks up the routine of the lecture.

7 Discussion can improve students' group interaction and communication skills.

8 In student-centered discussion students can be leaders and can teach other students.

9 Discussion is more likely to lead to commitment to a field (McKeachie, 1983).

10 Discussion does not have to be a "big deal" and can be included in a class which basically follows the lecture format.

There are disadvantages to discussion:

1 "Developing the ability to conduct effective discussion is even more difficult than learning to lecture effectively . . ." (Eble, 1988).

2 The process can be time-consuming and the rate of transfer of information is low.

3 Students do not show improved learning of knowledge, comprehension, and application objectives.

4 It may be difficult to obtain student participation, particularly in engineering.

5 Students must know something before an intelligent discussion is possible.

6 The instructor has less control and may be uncomfortable with the method.

7 Entire group discussions are not possible with more than about twenty students and work best with ten students or fewer (Davis et al., 1977). This problem can be surmounted by using small student-led groups.

8 The discussion approach may be less acceptable to students, particularly engineering students who want to learn from an expert.

9 Meaningful discussions may be difficult with immature students.

10 Engineering students often think that group interaction and communication skills should be taught in another class, not in engineering classes (Hayes et al., 1985).

Engineering classes often include objectives which can be appropriately taught by using discussion methods. For example, evaluation and comparison of competing designs, evaluation of unproven scientific theories or data such as "cold fusion," and determining the best way to allocate scarce resources are all appropriate topics for discussion. If one of the course goals is to help students define and explore problems to develop a variety of solutions, then brainstorming (see Section 5.6), which can be considered a type of discussion method, is appropriate. Small cooperative groups, which are appropriate for other aspects of problem solving (see Section 7.2), include a significant amount of discussion. Ethical dilemmas seldom have clear-cut answers and so are appropriate for discussion classes. Discussing ethics in class is also one approach to changing attitudes and possibly producing ethical engineers. Although the ethics dilemma does not have a correct solution, there are many incorrect solutions and students can learn to recognize them. If communication, interpersonal, or leadership skills are on your agenda (and many engineers in industry think they should be), then discussion methods are one of the appropriate teaching methods. If you want the students to be more active, to develop their higher-order processing skills, and to pay attention during the lecture, then question and discussion periods of five to ten minutes can be inserted in the middle of lectures.

7.1.2. Conducting Discussions

Conducting discussions is an art, for good discussions don't just happen; paradoxically, they must be structured to occur spontaneously. And this is why conducting excellent discussions is difficult. Discussion experts (Cashin and McKnight, 1986; Davis et al., 1977; Eble, 1988; Lowman, 1985; McKeachie, 1986) have a variety of suggestions concerning what to do to improve discussions. First, the professor must prepare for the class. Since discussion classes can wander through a broad range of material, the professor needs broad knowledge in the area. In lecture classes the professor can be one lecture ahead of the students, but in discussion classes this is not generally true. At the beginning of the class period the professor needs an agenda for the discussion session, even for only five minutes of discussion. It does not work to tell the students, "Let's discuss . . . ," followed by silence. Until they have been trained, engineering students won't know what you want. If you plan on using discussion techniques anytime during the semester, start early. Students expect the entire course to be similar to the first two weeks, so you need to have some discussion during the first two weeks, even if just as brief breaks in a lecture class.

Engineering students are generally very task oriented, so give the students a task. For example, "We have discussed the engineering and political factors which affect the siting of new airports. You have all studied the siting of a new airport for Chicago. Let's see if we can come up with a consensus of where to put the new airport." Note that the purpose of the discussion is really not to find a solution. The purpose is to expose the students to the process of reaching a solution. In the give and take of a good discussion on this topic, the students should learn something about the interaction between engineering and politics, about communication, and about the process of obtaining a consensus. This topic would also be useful for a panel discussion (see Section 7.3.1) or a debate (see Section 7.3.2). Since the process will be different in these three techniques, they complement each other.

Engineering students tend to enjoy problem-solving discussions. However, the discussions tend to become fragmented since students present comments at different stages of the problem-solving strategy. As the professor, you can exercise some control. Break the problem into parts and clearly tell the students which part to discuss. If a large class is broken up into small groups, the instructions to the small groups can clearly state: "Now that we have defined the problem, let's explore alternatives by brainstorming. You have three minutes." The leader ensures that everything stays on track either in the big group or in the small groups. Note the time constraint. If the purpose is to learn the process, a long period is not required since the lack of a complete solution is not a major problem. There is another advantage to the time constraint. If a group gets off track, it isn't allowed to go very far astray before being called back on track.

Particularly in large groups, the first contribution is the hardest. Be patient. If silence doesn't work (and at least two or three minutes may be needed), there are some alternatives. Ask a student to share a comment that he or she has made earlier. Since this is essentially a prepared comment which already has instructor approval, it is less threatening than having to volunteer something new. Make a provocative statement yourself. Challenge but don't threaten the students. Prepare ahead of time by planting a comment with a student or a TA. We suggest this be done only very early in the semester since this procedure can backfire. Say something encouraging like, "I'd really like to hear someone's opinion," and then try more silence.

If the difficulty in getting a discussion started keeps you from using discussions, you can always revert to questioning, but before doing so try dividing the class into small groups for discussions. Many students find it much easier to talk in small groups, particularly when the instructor is not sitting at the front waiting to pounce on the first remark. This is especially true of women students (Tannen, 1991). Many students participate when they feel the responsibility to do so, and the instructor can include this responsibility in the charge given to small groups. "I want each group to be sure that every student has the opportunity to speak." Finally, regardless of what the instructor does, some of the small groups will work. As the noise level in the room increases, other groups will start to talk.

Once students start talking, the instructor needs to be encouraging and accepting both verbally and nonverbally. The comments in Section 6.4 are all appropriate for discussion, except that it is not necessary to respond to each comment in turn. Let several students talk and let students respond to each other. In lectures the instructor talks—discussion is the students' chance.

What does a professor do? Davis et al. (1977) suggest several techniques which can be useful for working with the entire class once the discussion starts.

1 Post ideas on the board and verify the ideas. This allows you to use correct jargon. It also gives you something to do other than talk.

2 Serve as a gatekeeper to keep students on the topic. It's easier to keep students on the topic if the assignment is a clear task which has been broken into parts. You can exert some control by calling on students who raise their hands. Most students have been socialized through many years of school to talk only when called on. If you want to call on students who raise their hands, it is a good idea to enforce this rule so that everyone is treated equally.

3 When the discussion falters, request examples or illustrations.

4 Encourage and recognize contributions. The act of writing a contribution down is recognition. Also recognize contributions verbally: "Good!"

5 Test the consensus. Is the class ready to move on to the next part of the problem?

6 Summarize the discussion. To summarize the student discussion well you must listen. This is another reason to talk less.

The professor's role with small groups is discussed in Section 7.2.

What problems might arise? One is disagreement and conflict between students. Conflict can be resolved in a very positive way if the class is structured correctly (Johnson and Johnson, 1979). Early in the semester the instructor needs to set the climate that problems are to be solved together. That is, the discussion climate is to be cooperative and not competitive. There doesn't have to be a winner. There should be a firm rule that topics, not personalities, are to be argued. Students need to learn that they can agree to disagree and still have a high opinion of the other person. When conflict occurs, you should ensure that everyone has the same accurate information and then help the students to recognize similarities and differences. When this is done, it may become clear that the conflict is either over semantics or over one fairly small point. The result will often be a near-consensus. Another way to help students come to a consensus is to use the principles of debate and have them switch sides and argue for the other side. This works because students often see that the other side also has some valid arguments. If the conflict becomes heated, you need to deal with feelings either during or after class. Purposefully introducing controversy into a class is the topic of Section 7.2.3.

Nonparticipants are another problem. The discussion may drag if there are too many of them. Even if there are only a few, they may not be involved in the class and probably are not benefiting fully from the discussion. Quiet students may be quite involved in the material, but the other students are not benefiting from their input and the quiet students are not improving their communication skills. Pay special attention to these students to get their ideas and opinions. If a nonparticipant ever raises his or her hand, call on that student. If they are interrupted, come back to them. If they look ready to speak, encourage them verbally and nonverbally. These students may not speak because they are slow at formulating responses. Passing out one or two discussion questions as a homework assignment the period before may get these students past this barrier. They are more likely to participate in a small group, particularly if you specifically request that everyone participate. Women are less likely to participate in discussions than men, especially in a class where ideas are attacked (Tannen, 1991). They are likely to speak out more when asked for personal anecdotes or about what was useful to them in a reading or an assignment.

The overparticipant or monopolizer is another problem. In an instructor-led discussion the instructor can say that someone else's ideas need to be heard. This ploy often works since many students do not want to monopolize the discussion. If the monopolizing continues, you can call the student aside. We suggest trying a positive approach such as expressing concern about the person's need to work on listening skills. If the monopolizing behavior continues, a sterner admonition may be required. Once the group is comfortable doing discussions, the instructor may not have to step in to control the monopolizer. The other group members will tell the person to shut up, and they will often be stronger than an instructor should be.

Often the problems of nonparticipation and monopolization can be solved simultaneously by asking that each student speak at most twice during the class (Palmer, 1983). This forces the impulsive to slow down and weigh what they want to say. The resulting silences give the quieter students permission to talk.

Discussion should be considered part of the entire course. When the advantages of discussion are compared to the list of learning principles in Section 1.4, discussion by itself can satisfy some but not all of these principles. Discussions allow students a chance to be active, practice certain tasks, and provide feedback if they are willing to participate. The professor can easily communicate high expectations for the students and challenge them with thought-provoking questions and discussion problems. The class can be made cooperative, and in small discussion groups students can teach other students. Finally, the professor can certainly radiate enthusiasm. What discussion does not do efficiently is guide the learner, develop a structured hierarchy of material, and provide visual images. In addition, the practice, feedback, and challenges are only of one type and do not include detailed numerical calculations. Lectures, homework, and tests in addition to discussion can satisfy all the learning principles.

7.2. COOPERATIVE GROUP LEARNING

The topic of this section is cooperative group learning, not cooperative (or co-op) education which consists of alternating periods of work and of education on campus. In cooperative group learning students work together to understand the material, do homework, complete projects, and prepare for tests. Research has shown that a cooperative learning environment is conducive to learning higher-order cognitive tasks such as analysis, synthesis, evaluation, and problem solving (Johnson et al., 1991; Smith, 1986, 1989). Group work has long been common in engineering education in laboratory and design courses (see Chapter 9), and the Whimbey pair method for teaching problem solving discussed in Section 5.5 can also be considered a cooperative group method. What is new in this section is the use of groups for content-oriented classes which would normally be taught by lecture. We will start by considering informal learning groups, extend our comments to formal learning groups, and finish with a discussion on structured controversy.

7.2.1. Informal Cooperative Learning Groups

Informal cooperative learning groups are "spur-of-the-moment" groups formed for a particular short-term task and then dissolved. Their direct ancestor is the "buzz" group which has been commonly used for discussion for many years. Informal groups can be quickly formed in the middle of a lecture and students can be assigned a task such as solving a problem, answering a complicated question, or developing a question for the professor. These groups serve as a way to encourage students to be active in a large lecture class, provide for discussion, serve as a break when the students' attention starts to falter, and provide a more cooperative atmosphere in the class. In addition, these small groups have a modest number of students teaching students and provide students with an opportunity to practice teamwork. Inclusion of a short break from lecture with an informal group helps to individualize the class for the extroverts and field-sensitive individuals.

Informal cooperative groups also allow you to start experimentation with cooperative learning. Including these groups within a lecture class is not difficult and takes no more preparation time than the lecture. Since the groups are informal, assignment into groups can also be informal. We have found that the easiest thing to do at the start of the semester is to have students cluster in groups of about four based on choosing students who are sitting close to each other. This can be done in a normal lecture hall, although lecture halls are not ideal for discussions. The first time the class breaks up into small groups the professor must be very directive. A solitary student should be assigned to a group even if the student has to move. Later in the semester you may want to experiment with different groups. There is an advantage in having students move and work with students they do not know. Since small group dynamics are different in same-sex groups, you may also want to experiment with groups of the same gender (Tannen, 1991).

Once the groups are formed, tell the students to briefly introduce themselves to each other. You may want to assign a leader and a reporter, or let the group act informally. If no assignments are made and you notice that the group is not working, you can assign a discussion leader to get things going.

As the professor you must structure the small group experience and provide an agenda. Give a clear problem statement and a deliverable. Although the groups are formed on the spur of the moment, your agenda must be preplanned. As noted in Section 7.1, asking students to discuss a topic is not sufficient. The task for small groups should fit the following (Hamelink et al., 1989):

1 Have several possible solutions.
2 Be intrinsically interesting.
3 Be challenging but doable.
4 Require a variety of skills.
5 Allow all group members to contribute.

Hamelink et al. (1989) note that "if the task has one right answer or involves simple memorization then competitive education methods are far superior."

Most engineering students are pragmatic and want to do something, so there must be a deliverable. For example, if the problem is to come up with a list of five possible solutions, the deliverable is this list. If the problem is to come up with a consensus about some question, then the deliverable is the consensus. These deliverables should be presented to the entire class. If a reporter has been assigned, that student can make the presentation. Otherwise, let the group choose who will report, or call on a group member at random. Small groups should be told in advance how this reporting will be done. When the groups present, you can post the solutions on the blackboard or the overhead projector. Also note in advance that the first group to present has a major advantage since everything they report will be new. The last group may repeat items which have already been presented.

The problem statement should be very clear. Be sure to delineate what the deliverable is, either orally or with written instructions. If different groups have different instructions, then written instructions will probably be less confusing. Tell the groups roughly how much time they have. Then, say something like, "Let's get started. I want to hear some noise."

During the group discussion the professor and the TA can circulate among groups. If a group is working well together, there is no need to interrupt. Groups which have trouble getting started need a little help. A group with only introverts may have trouble. In the future you can mix the groups up and avoid the exact grouping which caused the trouble. At this time you might want to assign a discussion leader and a recorder to get things started. (One nice thing about informal grouping is that problem groups last for only about 10 minutes, and the next time the class can start over with new groups.) The instructor should also watch the time. Although it is not necessary for students to finish the task (Felder, 1990), we find being assigned a task with no chance of finishing to be frustrating. Thus, we like to watch the groups and to close the discussions when about half of the groups are essentially finished with the task. The entire process, including the reports to the whole class, can be completed in 10 to 15 minutes. Thus, informal groups can be conveniently inserted within a lecture.

These informal groups can satisfy many of the learning principles discussed in Section 1.4, and they also provide for some individualization in teaching style. They can satisfy most of the five elements necessary for cooperative group success (see Section 7.2.2). Cooperative groups help make the class seem more friendly and thus help the professor establish rapport with the students. Finally, informal groups are simple to implement and thus are a good approach with which to start.

7.2.2. Formal Cooperative Learning Groups

Formal cooperative learning groups are formed to teach each other and to work on longer-term tasks than are informal groups, even lasting for the entire semester. These groups often produce a project which is graded as a team effort. Since these groups are longer-term and grading is involved, a bit more thought might be put into forming and structuring them. Students who have worked in informal groups will have a good start in working in formal groups.

Getting started with cooperative learning groups can appear daunting at first since most professors have not experienced this teaching method. However, you do not have to convert the entire course to group work. Informal groups can be interspersed into the lecture, and one project can be done with a formal group. Then as you become more familiar with the strengths and weaknesses of this approach, you can convert more or less of the class to cooperative groups. Step-by-step procedures for getting started are outlined below (Smith, 1986):

1 As the instructor, you need to have clear objectives and a plan. The clearer the objectives, the easier it will be to get the groups started and functioning well.

2 Assign the students to groups. Smith (1986, 1989) suggests the use of random groups, while Goldstein (1982) recommends placing one good and one poor student (based on grade point average) into each group before randomly assigning the other students. Johnson et al. (1991) suggest even more instructor control, with high- medium-, and low-achieving students in each group. Both good and poor students can benefit from working together. The good students will teach the poorer students, and both will benefit. If the groups are to do significant discussion, there is also an advantage to having groups which are all women or where women are not in the minority (Tannen, 1991). All-women groups give women a chance to practice leadership. However, at least during part of the semester men and women need to be together in groups since they need to learn to work together; men, in particular, need to learn to work with a female team leader. Other criteria which can be used in selecting groups are discussed in Section 9.1.2. Depending on their purpose, groups should have from two to six students. Topping (1992) suggests starting with dyads since the teacher has more control. The class should meet in a room with circular or square tables, so that the groups can sit facing each other.

3 Carefully explain the task of the group. Early in the semester be very explicit about the task and the job of the group. It is desirable to promote interdependence. That is, one student cannot get a good grade when the group fails to perform its task satisfactorily. Thus, the grading procedure needs to be explained carefully. Some students will resist being graded on the results of the entire team. The rationale for this is that most industrial jobs are too big to be done by individuals and teamwork is a necessity. The team must function together to get the job done correctly and on time. Students might as well get used to the concept of teamwork now. If projects are chosen to be large enough that one student cannot complete them in the time available, there will be less complaining. Teamwork and cooperation should be emphasized in this explanation.

Grading on tests should also be carefully explained. One option is to give group take-home tests with each group receiving a single grade. The students can also be tested in pairs where time is available to confer with one's partner (Buchanan, 1991). If individual tests are given, it is important not to grade on a curve since grading on a curve fosters competiveness, not cooperation. Either mastery or a fixed scale should be used for grading individual tests. The professor can also assign bonus points to group members if everyone in the group gets above a cut-off score. (Johnson et al., 1991).

4 Monitor groups to ensure that everyone is working together and intervene if there are problems. You may need to know something about group dynamics to help groups if there are problems. Also, you may want to impose some structure on the groups such as requiring that everyone contribute once before anyone can contribute a second time. Or the recorder can be asked to keep a running account of the number of times different students speak. You and a TA can circulate and serve as resource persons when the groups are unsure about something. If there are technical problems, caution the students to check something or give a mini lecture to explain a complicated point.

5 Provide closure to the group session. Ask the students in each group to prepare a summary of their results for that day. If appropriate, ask for an outline of their future plans. Provide homework or additional assignments for the group.

6 Evaluate the achievements of each group and of the individuals in each group. Discuss with each group how well they are collaborating. Give them advice on how to improve. Students who have been pitted against their fellow students for years cannot be expected suddenly to blossom as cooperators without some practice and guidance. Be sure that class grading does not reinsert competitive behavior into the class. For example, individual tests can be mastery (see Section 7.4.1) or can be graded on an absolute scale. Group grading strategies are discussed in Section 9.1.

Now that you no longer spend the bulk of the time lecturing, what do you do? First, set clear objectives and provide learning materials such as a clear textbook, articles, and a study guide. As noted in Chapter 6, this plus a test is sufficient to ensure that students will learn the lower-level cognitive objectives (Taveggia and Hedley, 1972). You may also want to give different students different material to master. Then the contributions of all group members are essential for the group to have the complete picture.

Next, develop the activities the students will do in class and out. These are projects and open-ended problems with a clear deliverable. Problems must be challenging yet solvable with the basic principles, be realistic and attention-grabbing, and have multiple solutions. Particularly, early in the semester problems should be clearly defined. Later in the semester definitions can be quite vague.

Third, set up the groups and get them started. A good start will convince many otherwise skeptical students that they can learn efficiently in a cooperative group. It is important that the first problems not be trivial or closed-ended because at least the better students can do these more efficiently on their own.

During the functioning of the groups, the professor and the TA are both resource persons and troubleshooters. The professor can help when a group is struggling technically. This is important early in the semester when many groups want reassurance that their path is correct. Some groups will click, and some won't. The professor needs to help groups which aren't functioning well. There are several things that you can try. Remind them that the evaluation is a group evaluation and then let the group muddle through. It may be helpful to provide more structure to a group by assigning a group leader for this set of problems, or to focus on what the students are doing and remind them to do one problem solving step at a time. (This is the same procedure as that used in Section 7.1.2 for discussions.) You may also want to watch the interaction patterns for a while and then discuss group dynamics with the group. Finally, the groups may need to be shuffled. During this process of working with the groups, monitor the contributions of all group members.

The professor also serves as a time keeper and moves the group onward through a series of tasks. Students who are not experienced in working in groups often need to be guided through the process. The professor must also be sure that there is time for the group reports to the entire class, and that there is time for group processing at the end of the period.

An alternative group problem-solving procedure is a group-based socratic approach (Felder, 1990). Groups are given a problem to work on in class. Then a series of questions are used to guide the students toward the solution procedure. Students are given short periods (two to three minutes) to work on each question. This is followed by a brief discussion, with the instructor providing the answer if the groups have not had time to finish. The groups are then asked the next question in the sequence required to solve the problem. This procedure gives the professor considerable control and ensures that every student will be active and no student will become totally lost. However, it does reduce group interactions and group responsibility. This type of strongly directed group process is probably beneficial for freshman and sophomore classes where considerable direction is still desirable.

One advantage of cooperative groups is that the professor focuses on what the students are doing, not what the professor is doing (Astin, 1985). Since the students are the ones who must learn, this focus is appropriate. The group procedure also encourages most students to be active.

Five elements of group success, which should be remembered when groups are set up and operated (Smith, 1989; Johnson and Johnson, 1989; Johnson et al., 1991), have been identified.

1 Positive interdependence means that students believe that for one to succeed they must all succeed. The professor can promote positive interdependence by appropriate grading procedures, by making sure that that the group depends on the resources of all the students, or by requiring that a division of labor be used to complete the task. Early in the semester positive interdependence can be promoted by giving the group only one set of instructions.

2 Face-to-face promotive interaction means that students work together discussing, explaining, teaching, and solving problems. This face-to-face interaction promotes learning since it helps support the students' efforts to learn and motivates them.

3 Individual accountability and **personal responsibility** must be stressed so that an individual cannot "hitchhike" on the work of others without contributing. The professor can monitor attendance and contributions, call on students at random for presentations, and give individual examinations.

4 Social skills to work together are needed. Students need help in learning how to lead, teach, reach consensus, resolve conflicts, and communicate. For example, an engineering professor can encourage groups to check that everyone understands. Engineers in industry are expected to do these things, and students who learn how while in school will have an advantage on their first job.

5 Group processing is a necessary maintenance activity to keep a group working smoothly. What have members done to support the functioning of the group? What can they do in the future? Group processing can be checked by requiring each group to submit a summary of their processing. Johnson et al. (1991, pp. 3–10) help explain group processing by quoting Willi Unsveld, a mountain climber. "Take care of each other. Share your energies with the group. No one must feel alone, cut off, for that is when you do not make it."

There are gender differences in how people react in groups (Tannen, 1990). In general, women have been socialized to develop group rapport and to seek interaction. Thus, many female students are experienced in social skills and group processing. Male students, on the other hand, have been socialized to seek independence and not the interdependence necessary for proper group functioning. Thus, initial resistance and attempted sabotage of group work is much more likely to come from male students.

The results that have been achieved with cooperative groups include superior learning of higher-level cognitive processes and superior problem solving (Hamelink et al., 1989; Johnson, et al., 1991; Smith, 1986). In addition, cooperative groups report the formation of positive relationships and increased social support with the development of professional self-esteem (Johnson et al., 1991; Johnson and Johnson, 1989; Smith, 1989). Students in cooperative learning environments liked the subject more and wanted to learn more about it (Johnson et al., 1991). Cooperative learning also increases retention of students in college (Johnson et al., 1991; Tinto, 1987). In minority programs cooperative groups have led to greatly increased retention and a large increase in facilitators going on to graduate school (Hudspeth et al., 1989; Shelton and Hudspeth, 1989). Many students (and professors) are searching for an educational community (Palmer, 1983). Cooperative group education can deliver this sense of community.

7.2.3. Structured Controversy

Structured controversy is a special type of cooperative group in which students confront an emotional issue in a structured format and strive for a consensus (Smith, 1984). This procedure is useful for issues which combine technology and public policy. Appropriate issues for a structured controversy include the siting of roads, landfills, nuclear facilities, and government research centers; regulations for air pollution and control of acid rain; proposals to outlaw greenhouse gases such as Freon; and the legality of company rules which prevent women of child bearing age from working at certain jobs.

The professor first develops packets of materials with all the facts and with opinions both for and against. The packet in favor of one side has all the positive arguments and facts. The con packet has all the negative arguments and facts. A complete picture can be seen only by combining both packets. For many controversies there are organizations which have essentially already prepared either the pro or the con package. Normally, the built-in biases of materials from advocacy groups is a problem, but not in the structured controversy procedure.

The class is divided into groups of four students with one pair of students being assigned on the pro side and one pair of students on the con side. Each pair receives the appropriate packet and is told to study it thoroughly and to prepare a position statement. This preparation can be done as homework if the pairs can meet together. In the four-person groups each pair first presents its position. The other pair is told not to refute the presentation (this is not a debate), but to listen and ask for clarification. Then the issues are discussed. The other pair then presents its position while the first pair listens and asks for clarification. Then there is a group discussion where all four group members try to achieve a consensus position. The consensus positions are then reported to the large group, and an attempt is made to achieve an overall consensus position.

Before starting a structured controversy, the professor needs to state the discussion rules clearly. These rules are the same as those for handling controversy in discussion (see Section 7.1.2) (Johnson and Johnson, 1979). Ideas, not personalities, are argued. The focus is on attaining the best group decision or consensus, *not* on winning. Listing, restating, understanding and integrating all facts—this is forced by the structure of the groups since no side has all the facts. All sides must be understood, and evidence used to determine logical fallacies in the positions. Finally, everyone must participate.

It is useful to give the students specific rules for reaching consensus. Palmer (1983) lists the following:

1 *Do not* argue to achieve your rankings or solution.

2 *Do not* change your mind just to avoid conflict. Be suspicious of too rapid agreement.

3 *Do not* use coin flips or majority votes. These do not represent consensus.

4 When there is a stalemate, search for a compromise position which is acceptable to all parties. However, do not reward a member for finally agreeing by giving in later.

5 Look at differences of opinion as healthy and natural. These differences of opinion help the group arrive at a better final decision.

6 Use consensus procedures with groups where the members are comfortable with each other.

With a procedure like this it is the process and not the answer which is important. Thus, after the group discussion the professor should clearly set out the procedure and the rules which make reaching a consensus possible. Experience in activities such as this should make engineers much more effective communicators when working with the public on controversial issues.

7.3. OTHER GROUP METHODS FOR INVOLVING STUDENTS

In this section we will briefly explore three other group methods which can be used to involve students: panels, modified debates, and "quiz shows." These methods are useful as breaks in a lecture course and often serve as marker events for students. Thus, they are useful additions to the teacher's bag of tricks. However, we would not recommend using them for the entire semester.

7.3.1. Panels

The use of a panel consisting of three or four experts is a good way to start a question-and-answer period about a topic which has more than one correct answer. Professional seminars often use panels on topics such as job hunting, interviewing, what the first year in industry is like, what industry wants from young engineers, obtaining research funding, and achieving tenure. Panels can also be used for controversial technical topics, particularly those where technology and policy interact.

First choose the topic and decide on the date for the panel; then pick the panel and obtain the panel members' agreement to participate. Each panelist should prepare a very short (three or four minute) presentation which can serve as a springboard for questions and discussion, and on the day before the session remind the panelists of the meeting and the topic. Tell the class ahead of time about the panel meeting and assign readings.

During the panel discussion, of which you are the moderator, introduce each of the panelists and ask for a brief statement. When the time has expired, gently ask for a summary and introduce the next panelist. When the last panelist has finished, ask the class for questions. If there are none, start the period with a question. Once the questions start you can control the session by calling on students. As many students as possible should be involved. It may be appropriate to ask a specific panelist to answer a question because occasionally one panelist will tend to monopolize the conversation.

An interesting alternative to this procedure is to assign students to the panel. The students are assigned the task of becoming an "expert" on a particular topic before the panel discussion. Serving as a panelist can be an alternate assignment to giving an oral presentation, serving on a debate team, or being on a quiz team. If the students are unfamiliar with panel discussions, they will need a clear set of directions, preferably written. The panelists will certainly become very involved in the discussion, and if a good topic is chosen, so will the class. The result will often be a much smoother class than having four separate oral presentations which are not directly connected.

7.3.2. Modified Debates

A variety of forms of modified debates are useful whenever there are two or more sides to a question. In our teaching class we debate the question, What is the best teaching method? One can also debate topics concerning resource allocation such as the site of a new airport or how much government money should go to super large science. One can structure a debate around competing designs or controversial technology. Reynolds (1976) found simulated historical debates useful in a class on the history of technology.

In a classical debate there are two teams with two members each. One side takes the pro side of an issue, and the other takes the con side. The debate pattern is affirmative-negative-rebuttal-rebuttal. Good debaters are taught to prepare for both the pro and con sides of the question. The argument requires inference based on reasoning. Evidence consisting of facts and the opinions of authorities is used to bolster the argument. In classical debates, there is little room for personal opinion and no room for personal attacks. Debaters are taught to attack the logic and doubtful facts of the opposition. Each team in a classical debate tries to win; it is not an exercise in cooperative consensus building.

Debate is an excellent way to involve students in the material, work on communication skills, and require group effort. Unfortunately, in most classes the classical debate approach involves too few students. More students can be involved by increasing the size of the debate teams and by having more than two teams. For example, in our teaching class one team champions lectures, another PSI, and another cooperative groups. In a debate on siting a new airport each team champions a different site.

Many ways of running a modified debate are possible. We have found three groups with three members each to be convenient. Students are assigned to groups in advance and are given the topic to support. (An interesting alternate for advanced students is to have them prepare for all positions without knowing in advance which side they will be for.) The groups are told that each student will talk for four or five minutes. The first speaker from each group is told to take an affirmative position and present only positive statements. After each group has presented its affirmative positions, a second speaker from each group takes a mixed affirmative and negative position. The last speaker rebuts any damaging statements from the first two rounds and summarizes the team's position. The teams decide who goes first, second, and third and what will be presented.

The professor must first assign teams. We try to balance the teams as much as possible. The professor must choose the topic and pick the sides. The rules of the debate are spelled out, and the idea of an argument backed by evidence is explored with an example. Reynolds (1976) also requires that debaters prepare a position paper in advance which is turned in immediately after the debate.

One of the nonparticipants can serve as the debate moderator. Others can serve as judges; this makes the entire class active participants. It helps to give the judges a rating sheet so that judging is somewhat uniform. We use a rating sheet with five 5-point scales: analysis, evidence, argument, refutation, and delivery. The rating sheets are collected, and the team with the most points is declared the winner.

In our classes debates have always proven to be marker events. The students prepare hard and try to win. The competitive nature of the debate is a strong motivator for many students even though the results have little effect on the their grades. A debate is also another opportunity to practice communication skills, to improve analysis and evaluation, and to work together in teams.

7.3.3. "Quiz Shows"

Another break in the usual routine is to use one class period as a quiz show following the format of Trivial Pursuit, Jeopardy, or College Bowl. This can be done with either individuals or groups. Students are told to become experts on the class material. The participants can be selected in advance, or at random on the day of the quiz show. As in most competitive activities, this procedure works best if the teams or contestants are evenly matched. The professor can act as moderator and ask the questions. The contestant who presses a buzzer or rings a bell first gets to answer the question first. Points are awarded for correct answers and subtracted for mistakes. The winner or winning team is the one with the highest score at the end of the show.

This format works best for knowledge-level questions since they have the most straight-forward one-line answers. The professor needs to generate the questions and answers ahead of time. A panel of judges can be selected from the noncontestant students to decide if answers are correct. Another noncontestant can judge which student was first at pushing the buzzer. Since this type of quiz show is intense, twenty to twenty-five minutes of the period is probably sufficient.

We have never had the opportunity to use this procedure in class (we have used Trivial Pursuit in a student fund raiser) but think it would be a good break in a class where the students have to learn a large number of facts. Because of the competitive nature of a quiz show, many students will prepare diligently to try to win.

7.4. MASTERY AND SELF-PACED INSTRUCTION

Requiring students to achieve mastery in each topic is an appealing idea. However, this concept is more complex than it first appears. Once the concept has been explored, two instructional methods utilizing mastery will be discussed: self-paced (the Keller plan) and instructor-paced mastery courses. This is a logical but not chronological sequence. (The development could have logically occurred in the order presented but did not. In engineering education the Keller plan became quite popular before the key element, mastery, was isolated.) This section is important since these teaching methods are the only methods which show a clear advantage in the amount students learn. The extensive review by Taveggia and Hedley (1972), which found no difference in learning based on content examinations, did not include mastery-type classes.

7.4.1. Mastery

Mastery is a very simple, yet powerful, idea: Make students understand material well before allowing them to move forward. For hierarchical material this concept makes a great deal of sense. For any material, retention is better and relearning is easier when material has been mastered. In addition, success is motivating and the opportunity to master a subject often convinces students that they can learn.

If mastery is to be required, the material must first be divided into units or modules and objectives must be developed for each unit. Then the students must be tested for mastery of the objectives. Students who have not mastered the material need prompt feedback and probably some type of aid in learning the material. Repeated tests may be required. Thus, in a mastery course all students could theoretically earn A's, but the time required would vary significantly. In courses graded on a curve, grades correlate with ability, while in a mastery class the time required correlates with ability (Bloom, 1968; Stice, 1979). The need for repeated tests requires some modification in class schedules. Two different ways to do this are discussed in Sections 7.4.2 and 7.4.3.

What does mastery mean? For simple, lower-level cognitive objectives an unequivocal definition is easy. For example, the student can spell 100 words perfectly, or the student can quote the Gettysburg Address, or the student can repeat the definition of technical words without error. Since 100 percent is not required to achieve an A when straight-scale grading is used, mastery can be defined as 90 or 80 percent accuracy. Once the number (80, 90, or 100 percent) has been agreed on, it is easy to determine if the student has mastered the material.

But how does one determine mastery for higher-level cognitive objectives? In engineering most problems involve either application or analysis. Even for relatively simple technical concepts an infinite number of problems can be generated. How does the professor decide if the student has mastered the material? This question has been argued strongly by critics (e.g., Gessler, 1974). We think these arguments miss the practical point. Any professor who routinely awards partial credit for problems can separate student tests into mastery, near-mastery, questionable, and not-mastered piles. The near-mastery pile includes the tests of students who clearly understand the theory and how to apply it but have made a mistake in algebra or arithmetic. These students should probably be allowed to move forward. Students whose examinations are placed in the questionable pile can be talked to individually to see if they understand the concepts. Alternately, they can be told to study more and take another test—the only penalty is time, not a grade. Our conclusion, based on nine years of experience with mastery tests, is that there is no practical difficulty in using mastery learning for application and analysis problems in engineering.

Synthesis problems may present a practical difficulty. However, grading synthesis problems or grading for creativity presents a practical difficulty with any grading scheme. Our pragmatic solution has been to include a few synthesis problems where appropriate and then to score them very leniently. Mastery is probably not an appropriate grading scheme for design courses which include a significant amount of synthesis.

A second major question is, Can all students master the material if given sufficient time? The answer is probably no, but the percentage who can is much higher than the percentage that do with other teaching methods. Bloom (1968) found that 80 to 90 percent of the students in a mastery class could achieve test scores which would have given them an A in a lecture class (where 20 percent earned A's). In many engineering classes concrete-operational thinkers (see Section 14.1.1) will be unable to master the material. There are also students who could master the material but are unwilling to work hard enough or decide they do not want to be engineers. The vast majority can and do master the material. As a rough rule, Bloom (1968) thought that 90 percent of students can benefit from mastery learning, 5 percent will stumble, and 5 percent will master the material with any teaching technique.

If we adopt the concept of mastery learning, what is good instruction? Instruction which helps the student efficiently master the objectives is good instruction. This means that instruction must be individualized. Bloom (1968) states that the optimum would be a talented, dedicated tutor for each student. Before dismissing this as utopian, note that throughout grade school and high school many middle-class students have exactly this situation—their parents tutor them. The Keller plan can come close to reaching this ideal (see Section 7.4.2).

There are a host of practical questions. How big should the modules be? What are the important objectives? (This question should be asked in every course regardless of the teaching method used.) How does one arrange the schedule to allow for test retakes and extra learning time? If almost everyone masters the material, how does the professor grade? What method is used for presenting content? How do students receive feedback? How do students receive help if they do not understand a concept? These practical issues are discussed in Sections 7.4.2 and 7.4.3.

The results from many different types of mastery courses show that based on tests students learn more than they do with other teaching methods (Bloom, 1968; Hereford, 1979; Kulik et al., 1979; Stice, 1979). The previously cited extensive comparison of teaching methods (Taveggia and Hedley, 1972) found no differences between teaching methods in the amount students learned, but did not include mastery courses in the comparisons. In addition to learning more, students in mastery courses like the subject, are motivated to learn, and have an improved self-concept.

All teaching methods have disadvantages. These will be discussed when the detailed course types are considered in Sections 7.4.2 and 7.4.3.

7.4.2. Self-Paced Courses (Keller Plan or Personalized System of Instruction)

Self-paced courses handle the scheduling problem by letting students decide what pace they want. They are allowed to take mastery tests whenever they wish and thus can move through the course at their own pace. Several variants of the self-paced or personalized system of instruction (PSI) have been adopted in engineering. It is useful to consider the basic plan which was first developed by Keller (1968) in a psychology course.

What the student first sees in a Keller plan course are a course outline and a set of instructions. The student then gets a study guide and studies alone or in groups. When ready, he or she reports to a proctor and takes a test. The proctor grades the test with the student present. If the test is in the uncertain category, the proctor asks the student a few questions. If the student passes, the proctor marks the student as passed and gives him or her the next study guide. If mastery has not been achieved, the student studies some more before returning to take a different test on the same topic. The student continues to take tests on the area until the topic is mastered. After each test he or she automatically receives some tutoring as the proctor points out the mistakes and explains why the answers are wrong. After all required units are completed, there may be optional units and/or a final examination. A Keller plan course has the following six recognizable characteristics:

1 The course is self-paced. In the pure form no pressure is put on students to complete units at a given time. Many professors have found that for practical reasons students need to be encouraged to complete modules at some minimum rate.

2 The course is modularized, there are clear objectives for each module, and learning materials such as a study guide and a textbook are available. Clear objectives and the availability of learning materials are the necessary and sufficient requirements so that students learn as much as with other teaching methods.

3 Mastery. Mastery appears to be the key reason why students in PSI courses learn more than in nonmastery courses.

4 Undergraduate proctors as tutors to grade mastery tests and provide immediate feedback and help to students. The use of undergraduate proctors is extremely helpful and is appreciated by the students taking the course. Proctors can approach the ideal of providing individual tutoring for each student. In addition, the proctors learn a good deal and often become motivated to go on to graduate school. However, proctors do not seem to be essential for success as long as there is reasonably rapid feedback and help is available.

5 Lectures and demonstrations are used for motivation but not for transfer of basic information. This is clearly not necessary for the success of students using the method, and in instructor-paced classes lectures can be used for information transfer (see Section 7.4.3). Lectures may be necessary for the success of the professor since it is widely believed that "teaching and talking go hand in hand" (Keller, 1985).

6 Written and oral communication are used for testing. It is clear that a mastery class can be successful with only written communication on tests, and we see no reason why only oral communication could not be used.

Based on over twenty-five years of experience and experimentation since Keller first tried self-paced courses, it appears that there are three successful ingredients:

1 The course must be modularized with clear objectives and available learning materials.
2 Mastery must be required, but the exact level set (e.g., 80, 90, or 100 percent) is not critical.
3 Prompt feedback is necessary.

Regardless of who does the grading and provides the feedback, one result of a mastery course is that poorer students are forced to obtain more practice and receive more help than better students. This is the reverse of what often happens in nonmastery courses. The other details used by Keller are not critical for success (of course, if self-pacing is not used, the course is not a Keller plan course but can still be a mastery course).

Many variations in grading have been used in PSI courses. Keller (1968) based about 75 percent of the grade on the number of mastery quizzes which were successfully passed and 25 percent of the grade on the final. There is no penalty for taking a quiz and failing it. Some professors have required that students complete all required sections and then have awarded an A when this was done. The course grade distribution was either an A or an F/incomplete. This procedure has been extensively criticized. Some professors award a C when the basic modules have been completed and allow students to work for a higher grade with optional modules, an optional final, or other optional learning activities such as computer programs. This is a type of *contract grading* where the student contracts to do a specified quantity of work to earn a grade. The professor can also base the entire grade on the final examination which the student takes after completing the required modules. Grades in mastery plan courses are usually higher than in nonmastery courses. Mastery courses have been criticized for this; however, since the students are learning more, why shouldn't they earn higher grades?

No longer a lecturer, the professor becomes a facilitator of learning and chooses the content to cover, develops the objectives, selects learning material such as articles and textbooks, and writes the study guides. The professor must write the mastery tests and decide what constitutes mastery. He or she supervises the proctors or TAs and checks the grading. In many schools proctors are hired, though in small classes the professor may do the grading. The professor helps to motivate students and helps with the tutoring, particularly when the student has difficult questions. The professor is responsible for selecting the grading scheme and for assigning the final grades.

Billy Koen of the University of Texas first introduced the method into engineering education in a nuclear engineering course in 1969. A very wide variety of engineering courses have been taught by variations of the PSI method in every engineering discipline (e.g., Baasel, 1978; Conger, 1971; Craver, 1974; Grayson and Biedenbach, 1974; Harrisberger, 1971;

Flammer, 1971; Koen, 1970; and Koen et al., 1985). Because of a variety of time, money and administrative constraints, engineering professors have often modified the standard Keller plan. Pressure is often applied to students to keep them progressing in the course. Most professors do not present the motivation lectures or demonstrations. A TA or the professor may substitute for the undergraduate proctors. Tests may be only in written form with no opportunity for oral explanations. Since these changes keep the three key components intact, these courses are usually successful.

As noted in the previous section, students learn more in PSI courses than in nonmastery courses, and students do better on common final examinations (Keller, 1968; Kulik et al., 1979; Stice, 1979). Stice (1979) found that 75 percent of students preferred PSI to lecture courses. Small classes received particularly high ratings (this is not a surprise; see Section 16.3.3), and ratings were high in all classes (Hereford, 1979).

There are some problems with self-paced courses. The first time a professor teaches a PSI course the time commitment is roughly twice that for a nonmastery course (Craver, 1974; Hereford, 1979; Stice, 1979). This experience has prevented some professors from continuing with PSI. The good news is that subsequent offerings take about as much professorial time as lecture classes. Proctor costs are real, and PSI courses may be a bit more expensive than other classes. Hereford (1979) found that proctor costs ranged from $16.11 to $50.80 per student with a mean of $33.60. Because of inflation these costs have undoubtedly increased. However, there are major benefits of using carefully selected undergraduate proctors, and if they can be afforded they are a plus.

One advantage of PSI courses is that students are not competing with each other for a grade. Thus, they can be encouraged to cooperate. However, in most PSI variations no formal effort is made to arrange for cooperation, and some students work through the course in total isolation. These students talk only to proctors, and if the student masters the material this contact may be minimal. This shortcoming can be overcome without compromising the PSI procedure by developing cooperative groups and encouraging students to work together.

Procrastination can be a major problem because it can lead to excessive drops, incompletes, and lower grades. Drops increase because students realize that they are far behind and feel that they cannot catch up. Incompletes increase if students are allowed to receive an incomplete if they don't finish on time. This can be controlled by allowing incompletes only if the student meets the university's requirements for an incomplete which usually means illness, involuntary military service, or death in the family. Grades often decrease since the grade is based on the number of units the student has finished. In addition, procrastination spreads out the tests students take. This is a burden for the graders since they must be expert in a wider range of material and must have more tests available. Procrastination is worse with freshmen and seniors and is much worse with instructors who are inexperienced in using PSI (Hereford, 1979). Clearly, there are things the instructor can do to reduce procrastination. Students can be told the rules on incompletes, and they can be given both an average rate of progress and a minimum rate of progress. The professor or proctors can call and confront students who fall behind. All of these are successful in reducing procrastination, but they do compromise the concept of self-pacing. Extreme measures to control procrastination lead to an instructor-paced course.

7.4.3. Instructor-Paced Mastery Courses

A variety of instructor-paced mastery courses have been devised (Block, 1971, 1974; Bloom, 1968; Stice, 1979; Wankat, 1973). In the original development of this procedure (Block, 1971, 1974; Bloom, 1968) the instructor used whatever group teaching procedure that he or she wanted. The students took regularly scheduled formative examinations which were scored but not graded. The instructor marked the tests as mastery or not mastery. For each problem missed the student received information about alternate learning resources to learn the material. This diagnosis of problems is the key step in this procedure. The learning resources could consist of specific passages in other textbooks, articles, programmed texts, audiovisual material, workbooks, and so forth. The use of an alternate to the first way the student has studied helps to individualize the instruction for each student. Students were expected to study and learn the corrective material on their own time. Since the formative tests were not graded and did not affect the student's grade in the course, students were encouraged to cooperate with each other and with the professor to learn the material. In other words, the class and the professor became a team that tackled the real enemy—the content to be learned. All the students proceeded through the course unit by unit at the same rate. Students who had not mastered a previous unit were also simultaneously studying the unit they had not mastered. At the end of the semester the class was given a final examination which was scored and graded. The course grade depended entirely upon the final. Bloom (1968) found that 80 percent of the students received A's on the same final that 20 percent of the students in a nonmastery course had received A's on. When the formative examination results were compared to the previous year as a measure of progress, 90 percent of the students received A's. In this case the instructor spent extra time on those topics with which students were having additional problems.

In an absolute sense mastery was not required in these applications as it is in PSI courses. The frequent formative evaluations and diagnostic feedback were apparently sufficient for the students to learn more than in a usual class. The course was also modularized and had clear learning objectives. Feedback to the students was highly emphasized and was individualized to help each student learn. Unlike the situation in PSI, the instructor did "teach" in addition to structuring the course. As in PSI, students were not competing with each other. This was true even on the final since the grade necessary for an A was predetermined by what students in a lecture class had achieved.

The success of this type of course calls into question the need to make students achieve exact mastery on every test, and also makes moot the argument about what mastery is. However, based on our experience, a few students slip through who do not know the material well, and they do poorly on the final. This can be prevented with a instructor-paced mastery class which requires students to pass each formative test.

Our experience has been in developing and using such an instructor-paced mastery course (Wankat, 1973). The course was developed as an elective course for seniors and graduate students. To avoid procrastination problems, which can be severe with seniors, students were forced to move with the instructor. Each week the first mastery quiz on the old material was given on Tuesday, a lecture on new material on Thursday, and a repeat quiz on the old material on Saturday. The results of the first mastery quiz were posted on Wednesday. Students who did not master the material were required to come on Saturday and had to turn in homework before taking the repeat quiz. On Saturday the professor and the TA graded the quiz while the student watched; the mistakes were explained so that the student did not repeat them. Because of budget constraints proctors were unavailable and the staffing was the same as for a lecture course. If students did not pass the first repeat quiz, they had to return the next Saturday. Because of university scheduling, the quizzes on Tuesdays were timed, but the Saturday quizzes were not. With this arrangement some students fell quite far behind. The insertion of a two-week computer design module with no new Tuesday quizzes in the middle of the semester allowed them to catch up. Students who mastered the twelve required modules received a C. They could improve their grades by exercising one of three options: writing a computer program, mastering an optional module in a maximum of three attempts, or mastering the final in one attempt. Many graduating seniors worked for a C or a B and did not try to earn a higher grade.

The instructor informally compared the results to previous years and found that the students learned more. In most years when the course was taught there were no D's, no F's, and no incompletes. There were slightly more A's, many more B's, and fewer C's than when the course was taught as a lecture. Student ratings were very favorable. However, students who earned C's thought that they had put in more work and learned more than required for a C in other courses. Interestingly, the mastery course took an unfavorable schedule (Saturday morning classes) and turned it into an advantage. Many students studied diligently to avoid coming to the Saturday class. The instructor's time requirements were very similar to those reported for PSI classes.

7.5. INDEPENDENT STUDY CLASSES: INCREASING CURRICULUM FLEXIBILITY

In its simplest form, an independent study class consists of a study guide, a textbook, and a final examination. A student follows the study guide, reads the textbook, works any appropriate problems, and takes the final examination when ready. The student's grade is determined entirely by the final examination. If the study guide includes detailed objectives and the textbook is well written, any student with enough self-discipline to work through the material should do well on test questions at the lower levels of Bloom's taxonomy. Obviously, this approach will not work well for fostering higher-level cognitive skills, communication skills, and teamwork. Although uncommon in engineering, such independent study courses are fairly common in the humanities and social sciences. Independent study courses have the advantage of ultimate flexibility in scheduling. It is not necessary that the student complete the course in one semester, and either more or less time can be used.

Many variants of the basic independent study course are possible. Lectures can be carried on radio or TV, and taped lectures may also be available. Then students have the option of listening to the broadcasts in addition to reading the text. This additional mode of information transfer may be useful to some students. The broadcast schedule can also serve to provide some structure and as an indication of how fast they must progress in the course.

Another variant of independent study is to have a tutor available to answer questions and check homework problems. Otherwise, the student's pace and learning are independent and the course grade depends on test results. We have used this procedure to satisfy a very important prerequisite requirement in the chemical engineering curriculum. No test was given, and no course credit was earned; however, students were allowed to take the prerequisite course as a corequisite. Because of the structure of prerequisites in chemical engineering, this procedure allowed transfer students to graduate in two instead of three years. Over about a ten-year period we have had very good success with this use of independent study in a select group of motivated students. Since these students were seeing the material in the required course for the second time when they took it for credit, it is perhaps not surprising that they tended to do well. The only quality control applied was the requirement that the tutor be a chemical engineer and sign a letter stating that the student had covered the required book chapters; the tutor also had to list the homework problems that were worked.

Various other independent study options could be useful in providing flexibility in otherwise inflexible curricula. In addition to allowing students to take a prerequisite course as a corequisite, independent study could be used to allow students to continue taking engineering classes after flunking a required course. This would be particularly useful at schools where courses are offered just once a year and would reduce some of the pressure on students and professors. The independent study course would again satisfy the prerequisite requirements only—the student would have to retake the course for credit when it was reoffered. Since the reoffering would, in effect, be the third time, many students would be able to pass an otherwise impossible course. Independent study options would also be of interest to select students during the summer or when on co-op assignments.

The professor's task in these independent study options is first to decide what the essential material is and then develop the key learning objectives for this material. Next he or she must determine the required sections of the book and some representative homework problems. Finally, if the option will be used for a credit course, the professor must select the test(s) that will be used to grade the student.

Independent project and thesis courses are fairly common in engineering. They often involve fairly close work with a professor or graduate student and may involve student teams (see Sections 10.4 and 11.4).

7.6. FIELD TRIPS AND VISITS

Field trips and visits to local facilities are an underutilized teaching method in most engineering courses. Seeing real equipment or manufacturing operations provides students with a concrete, visual, and often kinesthetic learning experience. Such first-hand experience can make abstract equations seem much more real, and the trips can be motivating to many students. These trips can also serve as marker events. (We remember field trips that were taken 25 years ago, while we rarely remember individual lecture classes.)

Unfortunately, many engineering professors believe the myth that a field trip has to be an all-day affair which requires much time to set up. Such longer trips are often necessary to see particular types of engineering operations. However, local trips to facilities on campus or at the university's research park can often be completed in one class period, or even part of a period, and can provide a useful supplement for many courses. For example, many freshmen or sophomores will benefit from a "field trip" to the senior laboratory down the hall. This can be done in the last ten or fifteen minutes of a class. A class studying power production can visit the university's power plant, which is also of interest to a class studying cooling towers. Classes in structures or foundations can visit the sites of new buildings or bridges. Environmental engineers can visit the local wastewater treatment plant. Industrial engineers can obviously benefit from visiting any manufacturing facility, but less obviously can also learn from seeing the university's printing and mailing rooms or from a visit to a local travel agent. Practical information on steam transmission can be found in the basement of many campus buildings. Many research laboratories have specialized equipment which will at least give students an idea of what something looks like.

Field trips and visits offer many advantages: They are often a welcome break in the routine, are visually and kinesthetically rewarding, are often marker events, and provide the concrete experience of seeing real equipment and engineering operations, which can be motivating, with "real" engineers explaining the equipment or operation. Disadvantages include the loss of time for covering content and the loss of some control of what happens. In addition, appropriate trips require work to set up and this must be done well in advance, long distance trips are very time-consuming and arrangements must be made for students to miss one day of classes, trips away from campus cost money and often the professor has to find an "angel" to cover the cost, and some students do not take the trip or visit seriously since it is not covered on the test.

Our experience has been that ten-to fifteen-minute visits are very useful motivators for sophomores. Longer field trips are useful for seniors who have not had industrial experience, but the scheduling can be difficult. Optional trips arranged by a student organization are a useful alternative, and students often have an easier time raising money. In our class on teaching methods visits to local audio-tutorial laboratories, computer teaching presentations, and laser videodisc demonstrations have been among the highlights of the semester.

7.7. CHAPTER COMMENTS

This chapter has been a smorgasbord of different methods which can be used either as part of basically a lecture class, as a break in a class, or instead of lecturing. All these methods try to involve the student with the content and work to make him or her active. The methods included here certainly do not exhaust the possibilities. With some creativity engineering professors can develop new variations to involve their students.

You may decide that you have no interest in using cooperative group or mastery techniques; however, both of these methods clarify the need for clear learning objectives. Cooperative group learning has emphasized that professors should focus more on what the students do and less on what the professor does. Mastery learning shows clearly that a criterion-referenced grading scheme can be used, and that professors do not have to grade on a curve. All these truths can be adopted in other teaching methods.

Introducing change in the classroom can be difficult. Professors cling to lecturing because it gives them power, minimizes risk, and is socially acceptable within their department. Many students also prefer known teaching methods because the known is more secure. If a new teaching method has been used previously, student acceptance can be increased by showing the improved grade distribution obtained with the new method as compared to the old method (Tschumi, 1991). Elective courses are a good place to experiment since professors are scruntized less and the students are all volunteers.

7.8. SUMMARY AND OBJECTIVES

After reading this chapter, you should be able to:

• Outline the use of and discuss the advantages and disadvantages of the following teaching methods.

Discussion	Mastery and PSI
Cooperative group learning	Individual study courses
Panels, debates, and quiz shows	Field trips

• Incorporate appropriate methods into an engineering class taught by lecture.

• Develop an engineering course taught by a method where lecturing is clearly a supplemental teaching method instead of being the major teaching method.

HOMEWORK

1 Choose a specific undergraduate engineering course which is normally taught using the lecture method. Determine how you can incorporate two of the teaching methods listed in the first objective in Section 7.8 into the lecture course. Explain what you would accomplish by doing this. Develop your script for one day using one of the methods, and for another day using another method.

2 Choose the same engineering course selected in problem 1. Determine how to teach it using a nonlecture method. Prepare a detailed script for two days of class.

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