“Adopting instructional practices that engage students in the learning process is the defining feature of active learning” (Prince, 2004, p. 226). Various active learning methods have in common that the student has to actually do something, not sit passively and listen to lecture. Since the students are active, it is much more likely that they will become engaged, which is a key to learning (Light, 1992). This is not a new idea—an 1828 report from Yale argued that “active teaching methods were more effective than passive methods such as lectures” (Centra, 1993). Studies in physics show that interactive engagement methods increase test scores by about two standard deviations, the improved learning is not due to spending extra time on the topic, and active learning improved conceptual understanding (see Freeman et al., 2014; Prince, 2004 and Koretsky et al., 2012 for references).

An extensive review of research by Felder et al. (2000) showed conclusively that the following eight methods improved instruction in engineering: (a) use instructional objectives, (b) show material is relevant (c) teach inductively, (d) balance concrete and abstract information, (e) use active learning, (f) use cooperative group learning, (g) make tests challenging but fair, and (h) show concern about student learning. Most active learning methods are more effective that lecture for learning higher level cognitive objectives (Prince, 2004) and mastery methods are superior for the lower level objectives (Bloom, 1968, 1984). The extensive metaanalysis by Freeman et al. (2014) showed that students in active learning classes had higher test scores and were less likely to fail than students in lecture classes. Active learning was effective for all class sizes although classes with less than 50 students had the largest effects. Active learning will also tend to reduce cheating because there are often numerous low-stake assessments (Lang, 2013; see Section 12.2). Additional references will be cited in the sections that follow.

Different active learning methods will produce different results. Menekse et al. (2013) studied the following active learning methods in a materials engineering course:

1. Individual active learning is restricted to the content. Examples include underlining passages in the text, physically handling the materials to feel differences (without actually doing experiments), and linking the material to everyday life.
2. Individual constructive active learning requires generation of knowledge that extended beyond the limits of the current content. Examples include self-explaining the material or explaining to another student (without dialogue), developing a key relations chart or concept map, posing a research question, designing a study, drawing and interpreting graphs, doing experiments, and using analogies to explain.

3. Interactive constructive active learning involves two or more students working in the constructive mode and interacting to share their learning. Proper use of the interactive active learning mode involved the students in co-construction of knowledge with appropriate challenges based on scientific evidence. Groups do not automatically do interactive active learning.

Based on the literature the authors assumed that all active learning methods would result in more learning than passive learning. Their results showed that both individual constructive active learning and interactive constructive active learning resulted in more learning than individual active learning. For relatively shallow questions or problems (knowledge or application level of Bloom’s taxonomy), individual constructive active learning resulted in more learning than interactive constructive learning. This result agrees with Hamelink et al.’s (1989) results (Section 7.4.1). For more complex problems or understanding that requires linking multiple ideas (e.g., analysis and higher levels of Bloom’s taxonomy), properly implemented interactive constructive learning was more effective than individual constructive learning. Our interpretation of these results is that efficient, effective instruction can start with individual constructive active learning, which tends to have less student resistance than interactive approaches, and then switch to interactive constructive active learning for more complex problems.

Active learning works, but are many faculty members using active learning methods? As part of their biennial survey of faculty, the Higher Education Research Institute at UCLA asked instructors which teaching methods they used (De Angelo et al., 2009). An abbreviated list of the results is presented in Table 7-1.

<table>
<thead>
<tr>
<th>Teaching method</th>
<th>2005 survey</th>
<th>2008 survey</th>
<th>2008 Survey Prof. Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperative Learning</td>
<td>47.8</td>
<td>59.1</td>
<td>66.3 Asst. 58.0 Assoc. 49.6 Full</td>
</tr>
<tr>
<td>Group Projects</td>
<td>33.3</td>
<td>35.8</td>
<td>40.3 Asst. 34.6 Assoc. 31.0 Full</td>
</tr>
<tr>
<td>Multiple drafts written work</td>
<td>24.8</td>
<td>24.9</td>
<td>26.6 Asst. 24.3 Assoc. 22.9 Full</td>
</tr>
<tr>
<td>Electronic quiz, immediate feedback</td>
<td>—</td>
<td>6.8</td>
<td>7.8 Asst. 6.4 Assoc. 4.7 Full</td>
</tr>
<tr>
<td>Extensive lecture, not student centered</td>
<td>55.2</td>
<td>46.4</td>
<td>43.3 Asst. 45.2 Assoc. 51.8 Full</td>
</tr>
</tbody>
</table>

Active learning works, but are many faculty members using active learning methods? As part of their biennial survey of faculty, the Higher Education Research Institute at UCLA asked instructors which teaching methods they used (De Angelo et al., 2009). An abbreviated list of the results is presented in Table 7-1.

Since faculty would mark that they used a technique if they used it a few times per semester even for short periods, the percentages add to much greater than 100%. Because only lecture has the qualifier “extensive,” direct comparison of the amount of use of the different techniques is not possible. However, the data clearly shows an increase in the use of most active learning methods and a reduction in the use of straight lecture. Assistant professors are most likely to use active learning methods and full professors least likely. Lattuca et al.’s
(2006) survey of engineering faculty also found an increase in use of active learning with assistant professors most likely to use active learning.

Section 7.2 discusses flipped classrooms, where students watch the lecture before class and use active learning methods in class. The discussion method of teaching (Section 7.3), fairly common in the humanities, is seldom used in engineering, but it can be a very useful supplement in lecture classes. In cooperative groups (Section 7.4) most of the learning occurs in small groups. This method has been used for the entire course or as a supplement in lecture classes. Problem-Based Learning (PBL) (Section 7.5) uses realistic problems to structure student learning of new material. A variety of other methods such as panels or debates (Section 7.6) can be used to spark student interest and encourage involvement. Mastery learning (Section 7.7) requires that students reach a particular level of mastery on tests but gives them repeated chances to do so. The Keller plan or personalized system of instruction method (PSI) employs mastery learning in a format that allows a student to control the rate of progress through the course. In individual study (Section 7.8), a student studies alone or with occasional tutorial help to satisfy certain objectives. Field trips (Section 7.9) can be used as part of any course to help meet the course goals. Service learning (Section 7.10) is a close approximation of working as an engineer, but with a community organization instead of a company. Section 7.11 explores what you can do if you are blessed with a tiny class. Conversion to active learning (Section 7.12) is challenging but worthwhile. Evidence will be presented that shows for which objectives active learning methods are more effective than lectures.

Chapter 8 looks at alternatives to the lecture which use technology such as TV and video, alternative active learning methods that use computers such as simulation and interactive computer-aided instruction, and the video or screencast methods to provide the lectures for flipped classes. Chapter 9 covers active learning methods commonly used for teaching design and laboratory courses, and Chapter 10 considers one-to-one aspects of teaching that also usually require students to be active. In this chapter we look at active learning alternatives in lecture classes.

7.1. 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:
  
  | Flipped classes | Service learning |
  | Discussion | Mastery and PSI |
  | Cooperative group learning | PBL |
  | 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.

7.2. THE FLIPPED CLASSROOM

Active learning methods are more effective than lecture for learning many of the ABET learning outcomes, such as interpretation of data, design, problem formulation and solution, com-
munication, and computer tools. There are courses in such areas as problem solving, design, and laboratory where very little material needs to be presented in lectures. In these courses it is easy to use the remainder of the class time for active learning methods. Active learning works for problem solving or other skills being taught because students have a chance to practice and receive immediate feedback (Lang, 2013). One way to improve problem solving is through deliberate practice (Section 15.5).

But how does one introduce active learning methods in content-heavy courses normally taught with heavy doses of lecture? How does one find time to use extensive amounts of active learning in content-heavy courses? One approach has been called a flipped classroom—expect the students to study the material or watch a lecture or screencast before the class meets and use the class for an active learning approach (Bergmann and Sams, 2012; Lang, 2013; Pinder-Grover et al., 2011). Flipping is not new. The method can be traced in the United States to the early 1800’s when the Thayer method was inaugurated at the U.S. Military Academy at West Point, New York. Cadets used textbooks to learn before class and then recited during class. The method is still in use at the Academy. We will not treat flipping as an active learning approach; instead, we consider flipping to be an enabler that allows the use of any active learning method in the classroom.

The pre-class lectures can be produced as videos or screencasts (see Section 8.2.4). Success of flipped courses requires that the students actually watch the videos/screencasts or read the textbook before class. If the majority of the class does not do the pre-class preparation, the active learning method will not be as effective, and the active learning portion may fail.

One method to ensure that students are prepared before class is to use some type of sensor that shows students are actually watching the screencasts instead of just turning it on and doing something else. The sensor can consist of questions (e.g., what is 3 + 5?) that the students must answer within 10 seconds. These questions are inserted randomly a few times in a 10 to 15 minute screencast. Students who watch the entire screencast will receive a small reward—usually a specified number of points. Of course, students will be able to beat this or any other system that checks they have watched the screencast. However, most students will not try to beat the system if the screencasts are relatively short and are obviously related to the course content and the live class periods.

An alternative or supplement to using a sensor is assessment of student pre-class work at the beginning of the live class. Assessment can be done with a short quiz that is handed in for grading or with clickers (Section 6.7.4). Since the students are seeing the pre-class material for the first time, they should not be expected to be experts with the material. Thus, assessment exercises need to be tailored to determine which students have studied the textbook or watched the screencasts without being overly detailed. Students who correctly pass the assessment should receive some type of credit such as points.

A naïve outside observer might believe that engineering educators would be very logical in their choice of pedagogy to use. This, of course, is not the case as engineering education goes through cycles and fads. In 2014 flipping is still in the fad stage. Although many of the active learning methods have been extensively researched and are known to result in superior learning of certain objectives, there is little research on flipping. Whether it is the best way or just one of many ways to make time for active learning in class is unclear. However, since flipping couples pre-class study and active learning, students who do both are spending a fair amount of time on task, and flipping has the potential to be effective.
7.3. DISCUSSION

There is ample scientific evidence cited that shows that discussion is not an efficient method for transmitting facts and data, particularly when compared to lectures (Cashin and McKnight, 1986; Davis et al., 1977; Eble, 1988; Lowman, 1995; Svinicki and McKeachie, 2014). For 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 show small improvements compared to lecture in teaching analysis, synthesis, evaluation, problem solving, and critical thinking (McKeachie, 1972). 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.

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 that 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 7.3.

Discussions and questions (see Section 6.5) 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 (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 (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 (Figure 7-1B) is intermediate between these two. 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 (Svinicki and McKeachie, 2014). In addition, student changes in attitude are highest in student-centered groups.

### 7.3.1. Advantages and Disadvantages of Discussion

All teaching methods have advantages and disadvantages. The method has to be appropriate for the material to be taught, fit the students, and fit 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 14.3) 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 that can be appropriately taught by 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 brain-
storming (see Section 5.7), 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 7.4), 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 is an appropriate teaching method. 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.

### 7.3.2. 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, 1995; Svinicki and McKeachie, 2014) have a variety of suggestions concerning what to do to improve discussions. First, you must prepare for the class. Since discussion classes can wander through a broad range of material, you need broad knowledge in the area. In lecture classes you can be one lecture ahead of the students, but in discussion classes this is not generally true. At the beginning of the class period you must have 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 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 them a task. The purpose of the discussion is not really to find a solution, but 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 7.6.1) or a debate (see Section 7.6.2). Since the process will be different in these three techniques, they complement each other.

Engineering students 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 made earlier. Since this is essentially a prepared comment that 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 by planting a comment with a student or a TA. Do this 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. 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 female students (Tannen, 1991). Many students participate when they feel the responsibility to do so, and you 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 you do, 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, be encouraging and accepting both verbally and nonverbally. The comments in Section 6.5 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.

Davis et al. (1977) suggest useful several techniques 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 7.4.

What problems might arise? One is disagreement and conflict among students. Conflict can be resolved in a very positive way if the class is structured correctly (Johnson and Johnson, 1979). Early on, set the concept that problems are to be solved together in a climate that is to be cooperative and not competitive. There should be a firm rule that topics, not personalities, are to be argued, and that students can agree to disagree and still have a high opinion of the other person. When conflict occurs, ensure that everyone has the same accurate information and then help the students to recognize similarities and differences. It may then become clear that the
conflict is either over semantics or over one fairly small point. The result will often be a near-consensus. Another approach 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 7.4.3.

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. 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 prior period 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 over-participant 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 talk to the student outside of class. Try using a positive approach, such as expressing concern about the person’s need to work on listening skills. Another approach is to ask students sitting in another section of the room to talk. Calling on a section instead of a single person diffuses the pressure to speak. Once the group is comfortable doing discussions, you may not have to step in to control the monopolizer. The other group members will tell the person to be quiet, 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. A variation of this method is to crumple a piece of paper into a ball. The student with the ball is the only one who can talk. When that student finishes, the ball is passed to another student.

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. You 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, you 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.
7.4. 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.

Cooperative group learning involves students, which leads to learning. It also helps students learn how to function in groups, which helps satisfy ABET criterion 3d (Section 4.7) and has been proven to result in superior performance in the top three levels of Bloom’s taxonomy. In cooperative group learning, students work together, do homework, complete projects, and prepare for tests. Largely because of the efforts of Karl Smith and the Johnson brothers, who introduced cooperative group learning into engineering in 1981 (Smith et al., 1981), cooperative group learning is the most studied learning method in engineering education. 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). 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 5.6 can also be considered a cooperative group method. What is new in this section is the use of groups for content-oriented classes that 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.

7.4.1. 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 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. At the start of the semester 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 you have to be very directive. A solitary student should be assigned to a group even if the student has to move. To form different groups, we like to have students count off 1, 2, 3 up to the number of groups desired and then move to sit with their group. Michael Loui (private communication) likes to give each student a card from a deck of playing cards. All students with the same number form one group. All students with the same suit (spades, hearts, etc.) have the same role. For example, the student with the spade is the reporter. 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 them to briefly introduce themselves to each other. 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 planned. As noted in Section 7.3, 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. If the problem is to come up with a list of five possible solutions, the deliver-
able 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. Also note in advance that the first group to present
has a major advantage since everything they report will be new. If a large number of groups
report, the last groups may repeat items that have already been presented. To avoid this, do
several short problems with different groups reporting each time.

The problem statement should be very clear. Be clear 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 you and the TA can circulate among groups. Groups that
have trouble getting started need a little help. A group with only introverts may have trou-le. In the future you can mix the groups up and avoid the exact grouping which caused the
problem. 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
5–10 minutes, and the next time the class can start over with new groups.) Also watch the
time. Although it is not necessary for students to finish the task (Felder, 1990), being assigned
a task with no chance of finishing can 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 5 to 15 minutes.
Thus, informal groups can be conveniently inserted within a lecture.

Perhaps the easiest groups to work with informally are pairs. For example, if an issue
appears to be confusing, ask students to check with their neighbor to check for understanding.
Then ask for more questions. Students will also have more accurate lecture notes if they are given two minutes to compare lecture notes with their neighbor. The Whimbey-Lochhead pair method for understanding problem solving (Section 5.6) is another pair method that can be done in large lecture courses.

These informal groups can satisfy many of the learning principles discussed in Section 1.5, 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 7.4.2). Cooperative groups make the class seem friendly and help you establish rapport with the students. Finally, informal groups are simple to implement and thus are a good approach with which to start implementing active learning techniques.

### 7.4.2. Formal Cooperative Learning Groups

Formal cooperative learning groups are formed for students 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 that 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) 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 that are all women or where women are not in the minority (Tannen, 1991). All-women groups give them 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. CATME is an easy to use online tool that is very useful for group selection, particularly in large classes (CATME, 2013; Ohland et al., 2006). Other criteria in selecting groups are discussed in Section 9.2.3. Depending on their purpose, groups should have from two to six students. Topping (1992) suggests starting with dyads since you have 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. 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 will have an easier time finding a job and integrating into the work force if they become good team members 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 competitiveness, not cooperation. Either mastery or a fixed scale should be used for grading individual tests.

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 7.7.1) or can be graded on an absolute scale. Group grading strategies are discussed in Section 9.2.

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, train the TAs or UGAs if you have any. To be helpful, they have to understand the problem and be trained in group facilitation methods.
Fourth, 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, you and the TAs are both resource persons and troubleshooters and 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. Help groups that aren’t functioning well. Remind them that the evaluation is a group evaluation and then let the group muddle through. 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 7.3.2 for discussions.) 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 and TAs also serve as time-keepers and move the groups onward through a series of tasks. Students who are not experienced in working in groups often need to be guided through the process. 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 operating (Smith, 2009; 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. Team discussions of individual student’s learning styles (Section 15.2) and Myers-Briggs preferences (Chapter 13) help students learn to work together (Heywood, 2005).

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) help explain group processing by quoting Willi Unseld, 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” (pp. 3–10)

In the US, Tannen (1990) found gender differences in how people behave in groups (Tannen, 1990). Speaking very generally, 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; Heywood, 2005; Johnson, et al., 1991; Prince, 2004; Smith et al., 2005, 2009). 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; Smith et al., 2009). 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, 1994), and increases student retention in technical subjects by up to 22% (Prince, 2004). 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). Many students (and professors) are searching for an educational community (Palmer, 1983). Cooperative group education can help deliver this sense of community.

However, there are caveats. Only mature, well-developed groups (groups that follow the five elements of group success) outperform individuals (Hsiung, 2012; Smith et al., 2005). The performance of team members improves as the team matures (Hsiung, 2012). Initially teams often under-perform individuals because of attention conflicts (the task work and team development interfere with each other). After a few weeks of practice and some training on group processes, the team development interference is no longer a problem.

### 7.4.3. Structured Controversy

In structured controversy the cooperative group confronts an emotional issue in a structured format and strives for a consensus (Smith, 1984). This procedure is useful for issues that
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 that 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 that 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.

Divide the class into groups of four students with one pair of students 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, state the discussion rules clearly. These rules are the same as those for handling controversy in discussion (see Section 7.3.2) (Johnson and Johnson, 1979). Ideas, not personalities, are argued. Students should focus 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.

It is the process and not the answer that is important. After the group discussion, 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.
7.5. PROBLEM-BASED LEARNING (PBL)

Problem-based learning (PBL) uses realistic problems to focus students on the content to be learned. It is usually done in cooperative groups. The distinction between PBL and project-based learning (Section 9.1.4) is based on whether the purpose is to learn new material (PBL) or to integrate and apply material already learned (project-based learning). Everyone who has taught design will realize that this distinction is not that clear-cut since students in design always have to learn a significant amount of new material to complete the design. Although some authors (e.g., Prince, 2004) draw a clear distinction between project- and problem-based learning, Du et al. (2009) consider the two methods to be closely related.

Prince (2004), Heywood (2005), and Woods (2012) note that since there are many variants of PBL it is necessary to closely define what version of PBL is used to determine the effectiveness of the method. Prince (2004) presents data for different aspects that may be part of a PBL course. The use of non-expert tutors reduces student learning significantly compared to the use of expert tutors. This result agrees with the significantly lower impact of untrained tutors in tutoring (Section 10.3). Self-paced and self-directed PBL courses had small decreases in learning compared to instructor-paced PBL courses. Apparently, students are enthusiastic at the beginning of self-directed courses, but when they realize that being in charge of their own learning is not as easy as it looks, their motivation drops (Heywood, 2005). Studies comparing PBL and lecture methods on test results show that students in an instructor-paced PBL course outscore students from a lecture course, but students from student-paced PBL courses had lower test scores than students from a lecture course. The largest learning gains were from cooperation, instruction in problem solving, and small groups.

Based on these results, a good PBL course would use small cooperative groups, explicitly train the students in problem solving, be instructor-paced, use problems with inquiry learning, and use either trained tutors or no tutors other than the instructor. This course would be likely to develop positive student attitudes, increase tendency to use deep approaches to learning, improve the problem solving and group interaction skills of the participants, increase ability to learn on their own, and increase retention of information. However, scores on paper and pencil tests would probably be very similar to those of students from lecture courses and less than those of students from a mastery learning class.

Woods (2012) focuses on the slightly different medical school model of PBL—a self-directed PBL in which the students receive a one-page description of the problem. Based on this description the team decides what knowledge they need, contract with each other what to learn individually, and then teach this material to the team. The best approach for solving open-ended problems is to have each group member attempt the problem individually before the group as a whole meets to discuss possible solutions. Since trained tutors were not available in his engineering courses, Woods preferred to have groups without tutors. This model will work best with mature, highly motivated learners. The students need to be prepared in advance for PBL with skills in problem solving, teamwork and self-assessment. Results at schools that train students ahead of time will be better than at schools that do not train, but the training may not be explicitly mentioned as part of the PBL program.

The amount of content to cover needs to be scaled back from a normal lecture class because a significant fraction of time (30 to 70%) needs to be spent on group activities (Woods, 2012). With reasonably well-functioning groups 80% of the coverage of a lecture course is appropriate.
This means the PBL course should focus on the important fundamentals. The students also need learning resources. Woods (2012) made videos of lectures, but the PBL students did not use the videos. Prince (2004) notes that short lectures can be very useful for imparting information. We expect that the difference is between self-directed and instructor-directed PBL.

PBL tends to be stressful on students, with much of the stress caused by the change from a well-known and understood method—lecture—to a novel and scary method—PBL (See Section 7.12). Listen to students and acknowledge the stress they are under. PBL will also be stressful on professors who procrastinate because a significant amount of work (collection of information, training of students) needs to be done in advance (Woods, 2012).

Other engineering PBL studies report additional positive results. Mitchell et al. (2010) noted that potential industrial employers were very interested in the experiences that students had in a PBL module. We have noticed a similar interest with service learning. A slight increase in grades in PBL compared to the lecture portion of the course was observed, but the biggest effect was the elimination of failures (Mitchell et al., 2010). Mantri et al. (2008) found “as the students gained experience in PBL and team work, progressive improvement in their knowledge, technical and communication skills, and attitude was observed.” PBL students spent more time in class, learned more, and developed better skill sets than students in a lecture course. Costa et al. (2000) reported, “In practice, the most important characteristic of the PBL method is that it creates a good learning atmosphere resulting in a positive attitude towards circuit theory and studying, in general.”

The Biomedical Engineering department at Vanderbilt University collaborated with John Bransford to use How People Learn (see Section 15.5) principles to design challenge-based instruction, which has many similarities with PBL. A definitive report (Roselli and Brophy, 2006) showed that students taught by this active learning method were significantly better at solving difficult problems than students taught traditionally.

7.6. OTHER GROUP METHODS FOR INVOLVING STUDENTS

There are three other group methods that 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.

7.6.1. Panels

The use of a panel consisting of three or four experts or prepared students 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. In a course for new TAs we have used panels of experienced TAs to discuss their TA experiences. 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 that 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 that will prepare them for the meeting.

During the panel discussion, of which you are the moderator, introduce each panelist and ask for a brief statement. When the time expires, 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. The problem of no questions can be resolved by requiring students to turn in a list of questions either the day of the panel or a week in advance so that the lists can be shared with the panelists. Once the questions start you can control the session by calling on students. Involve as many students as possible. 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 taking the course 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 unconnected oral presentations.

7.6.2. 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?” You can also debate topics concerning resource allocation such as the ideal site of a new airport or how much government money should go to super large science. You 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. The key to a good debate is to have a good topic (Heywood, 2005; Light, 2001).

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 mastery, 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 prepare for all
positions without knowing in advance which side they will defend. The groups are told that each student will speak for three or four minutes. The first speaker from each group takes an affirmative position and presents 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.

First, assign balanced teams one or two weeks in advance. Choose the topic and pick the sides. Spell out the rules of the debate, and explore the idea of an argument backed by evidence with an example. Reynolds (1976) suggests that debaters prepare a position paper in advance that is turned in immediately after the debate. We have each team provide a position paper with their positive and negative arguments.

At the beginning of the debate, the students pick from a hat the side they will defend. They then have six minutes to set strategy. 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.

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 their grades. A debate is also another opportunity to practice communication skills, to improve analysis and evaluation, and to work together in teams.

7.6.3. Quiz Shows

Another break in the usual routine is to use one class period as a quiz show following the format of Jeopardy or a game like Trivial Pursuit. 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. You 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 straightforward one-line answers. The professor needs to generate the questions and answers ahead of time. A panel of judges can be selected from the non-contestant students to decide if answers are correct. Another non-contestant can judge which student was first at pushing the buzzer. Since this type of quiz show is intense, 20 to 25 minutes of the period is probably sufficient.

Schrynemakers (2013) recommends a different format for challenging questions at the comprehension level of Bloom’s taxonomy. Develop and give to the student groups about 20 questions. Draw a race track on the board with about 10 segments. Use colored markers or sticky notes for each team. The rules are:

1. On their turn the group can choose to attempt to answer up to 3 questions.
2. To advance all attempted questions must be answered correctly. The group advances as many spaces as answered correctly.
3. The instructor tells the group only if they advance or not. If they advance all the questions they answered are retired.

4. After $n$ rounds ($n$ is decided in advance), the group that has advanced furthest wins.

An example question: If I want to cool my coffee from 99°C to 60°C as quickly as possible, when should I add the milk (which cools the coffee by 10°C)?

Since the groups don’t know which answers were wrong, there will be a significant amount of discussion while they try to determine correct answers. The contest also involves strategy—should a group answer a single question that it is sure of the answer or go for three questions?

We have never had the opportunity to use a quiz show or game 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.

### 7.6.4. Role Play Simulations

In many other disciplines such as business, finance, or policy studies a type of non-computer simulation is used in which students are given roles to play (Hertel and Millis, 2002). This type of simulation can be thought of as a case study (see Section 9.2.4) in which instead of studying the actions of a professional in trying to solve the problem, the students play the role of the professional. An effective simulation needs to be realistic or many students will not buy into their roles. Thus, a fairly elaborate scenario with a variety of roles needs to be developed. Mock trials have the advantage of being fairly easy to set up and they can easily include ethics or whistle-blowing issues (Heywood, 2005). The simulation also has to naturally incorporate course content or it is a waste of time. The simulation consists of one or more class periods in which the students play their roles. When set up as a simulation game, the students try to convince some organization with decision authority, such as a school board (also role played by students) to decide in their favor.

Since engineers are often involved in policy decisions, a role play of a controversial decision in which engineers play an important part would be an appropriate learning experience in an advanced course. For example, topics could include:

- Placement of a third international airport in Chicago.
- What to do with New York City garbage.
- How to treat the Gulf of Mexico dead zone at the outlet of the Mississippi River.
- How to prevent the increase in sea water levels from inundating a city during storms.

These topics have both an engineering component and a policy component.

Modified debates (Section 7.6.2) are an alternative teaching method for intertwined engineering/policy problems. Debates are easier to set up than simulations since debates do not need the elaborate scenario required for a successful simulation. However, the engagement that can occur in a simulation is stronger than in a debate.

Engineering design courses often have a small role play component since students are assigned to a fictitious company. To tap into the power of a simulation, the company scenario and roles would need to be described in significantly more detail.

In a realistic, properly developed simulation the students can get "sucked into" their roles. Since they become extremely engaged, the result can be a very powerful learning experience.
However, there is a potential downside. You need to control the simulation so that it does not stray into unethical regions. This danger arises because people will often do what “authorities” tell them to do. Even though the authorities in a role play do not have real power, other students will often do what the authorities order. This was dramatically illustrated in Stanley Milgram’s obedience experiments (Blass, 2004), in which subjects apparently applied electric shocks (the shocks were not real, but the subjects thought they were) to confederates (experimenters in disguise) who failed to answer questions properly.

7.7. MASTERY AND SELF-PACED INSTRUCTION

Requiring students to achieve mastery in each topic 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.) Unfortunately, engineering educators all ignored the paper by LePage and Lett (1954) that reported on experiments with lecture, instructor-paced mastery learning, and self-paced mastery learning and concluded that instructor-paced was the best method. This section is important since mastery teaching methods are the only methods that show a clear advantage (a statistically significant increase) in the amount students learn based on paper and pencil tests (Bloom 1968, 1984). The extensive review by Taveggia and Hedley (1972), which found no difference in learning based on content examinations, did not include mastery-type classes.

7.7.1. Mastery

Mastery is a very simple, yet powerful, idea: Ensure 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.

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. Theoretically, in a mastery course all students could 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, 1984; Stice, 1979). The need for repeated tests requires some modification in class schedules. Two different ways to do this are discussed in Sections 7.7.2 and 7.7.3.

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 repeat the definition of technical words without error. Since 100% is not required to achieve an A when straight-scale grading is used, mastery can be defined as 90 or 85% accuracy. Once the number (85, 90, or 100%) has been agreed on, it is easy to determine if the student has mastered the material.
Some topics lend themselves naturally to a mastery approach. As Koen (2005, p. 599) states, “Computer programming is an unforgiving, mastery-oriented discipline.” Thus, mastery “is an appropriate pedagogical technique to use.” We use mastery in computer labs for the related skill of using a commercial simulator on straightforward problems. Mastery is also appropriate in fundamental, building-block courses that cover material, such as mass and energy balances, that is used throughout the curriculum.

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 do you 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 twenty years of experience with mastery tests in lecture classes and in computer labs, 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.

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% of the students in a mastery class could achieve test scores that would have given them an A in a lecture class (where 20% earned A’s). In many engineering classes concrete-operational thinkers (see Section 14.2.1) 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% of students can benefit from mastery learning, 5% will stumble, and 5% will master the material with any teaching technique.

In mastery learning, what is good instruction? Instruction that helps the student efficiently master the objectives is good instruction. This means that instruction must be individualized. The optimum teaching method would be a talented, dedicated tutor for each student (Bloom, 1968, 1984). 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 or home-school them. The Keller plan can come close to reaching this ideal (see Section 7.7.2).

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 7.7.2 and 7.7.3.

The results from comparing many different types of mastery courses with other teaching methods show that based on tests, students learn more than they do with other teaching methods (Bloom, 1968, 1984; Hereford, 1979; Kulik et al., 1979; Stice, 1979). In addition to learning more, students in mastery courses like the subject, are motivated to learn, and have an improved self-concept. Note that the previously cited extensive comparison of teaching methods (Taveggia and Hedley, 1972) found, based on test scores, that there were no differences between teaching methods in the amount students learned, but they did not include mastery courses in the comparisons. All teaching methods have disadvantages. The disadvantages of mastery learning will be discussed when the detailed course types are considered in Sections 7.7.2 and 7.7.3.

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

An observer of the engineering education literature who takes a snap shot of educational methods at a given time might believe that the field is logical and unemotional. However, following the literature over a period of time shows that engineering education has fads and cycles. The Keller plan is an example of cycles in engineering education (Heywood, 2005).

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 course developed by Keller (1968) in a psychology course and introduced into engineering by Koen (1970).

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 gives her or him 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 and immediate feedback appear to be the key reasons why students in PSI courses learn more than in lecture 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. If undergraduate proctors are used, they must be selected carefully for both knowledge and empathy (Heywood, 2005).

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 7.7.3). 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.

There appear to be three successful ingredients of the Keller plan:

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., 90 or 100%) is not critical. Using 100% as the criterion may seem excessive, but this is the level of mastery that computer programming requires.
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 non-mastery 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% of the grade on the number of mastery quizzes that were successfully passed and 25% 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 non-mastery 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 (Koen, 1970). A very wide variety of engineering courses have been taught using variations of the PSI method in every engineering discipline (e.g., Heywood, 2005; Koen, 2002, 2005; and Pryor, 2012). 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 non-mastery courses, and students do better on common final examinations (Keller, 1968; Kulik et al., 1979; Stice, 1979). Stice (1979) found that 75% of students preferred PSI to lecture courses. Small classes received particularly high ratings (this is not a surprise; see Section 16.4.3), and ratings were high in all classes (Hereford, 1979).

There are some problems with self-paced courses. The first time with a PSI course the professor’s time commitment is roughly twice that for a non-mastery course (Hereford, 1979; Stice, 1979). This experience has prevented some 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. 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. In an online course the progress of each student can be monitored automatically (Pryor, 2012). The professor or proctors can contact 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.

### 7.7.3. Instructor-Paced Mastery Courses

A variety of instructor-paced mastery courses have been devised (Ahlgren and Verner, 2009; Block, 1971; Bloom, 1968; Richardson, 2010; Stice, 1979; Wankat, 1973, 2002). Originally (Block, 1971; Bloom, 1968) the instructor used whatever group teaching procedure he or she wanted. The students took regularly scheduled formative examinations that 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, screencasts, workbooks, and so forth. The use of an alternative 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. 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 that was scored and graded. The course grade depended entirely upon the final. Bloom (1968) found that 80% of the students received A’s on the same final that 20% of the students in a non-mastery course had received A’s on. When the formative examination results were compared to the previous year as a measure of progress, 90% 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, a few students slip through who do not know the material well, and they do poorly on the final. This can be prevented with an 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) and in using instructor-paced mastery in computer labs. The course was developed as an elective course for seniors and graduate students. To avoid procrastination, 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.

“Whatever the approach, mastery always has been the goal of learning. Perhaps it is time to give it another try” (Wankat and Oreovicz, 2001).

7.8. INDEPENDENT STUDY CLASSES: INCREASING CURRICULUM FLEXIBILITY

An independent study class consists of either a study guide, a textbook, and a final examination, or a reading list, weekly meetings with a tutor (usually a professor) and a final project report. In the first type of course 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 first type of independent study course are possible. Lectures can be made available online. Then students have the option of watching the lectures in addition to, or instead of, reading the text. This choice of mode of information transfer is useful for many students. The schedule for placing lectures online also provides some structure and as
an indicator of how fast students should progress in the course. This course may 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 a modified tutored 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 co-requisite. 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 had very good success with this use of independent study for 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, list the homework problems that were worked, and sign a letter stating that the student had covered the required book chapters.

Various other options for independent study courses could be useful in providing flexibility in otherwise inflexible curricula. In addition to allowing students to take a prerequisite course as a co-requisite, independent study could be used to allow students to continue taking engineering classes after failing 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.

The second type of independent study as a project or thesis course is fairly common in engineering. They often involve fairly close work with a professor or graduate student and may involve student teams (see Sections 10.5 and 11.5). The danger with an individual project independent study course is that the professor will stop requiring weekly meetings and at the end of the semester accept an inferior project report (Abbott, 1994).

**7.9. FIELD TRIPS AND VISITS**

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 45 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 that 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 (Davis, 2009). 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. In the multidisciplinary engineering program we have been very successful with local field trips to companies that are sponsoring design problems for the capstone design course (Section 9.2.4). 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 if it is not covered on a 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 student organizations can often raise money from sponsors for trip expenses. In our class on teaching methods, visits to local specialized teaching laboratories, and computer teaching presentations have been among the highlights of the semester.

7.10. SERVICE LEARNING

Service learning is based on the premise that students can use their knowledge, enthusiasm and energy to help community organizations while learning both the necessary knowledge and how to apply their skills to real problems. The term “service learning” (learning material while engaged in projects in the community) was coined in 1967, but the philosophy of learning while working has a much longer history (Barrington and Duffy, 2010; Jacoby and associates, 1996; Lima and Oakes, 2014).

Service learning is an active experiential learning process (Wankat and Oreovicz, 2001) that can be conceptualized with Kolb’s learning cycle (see Section 15.4). The concrete experience and personal involvement of working with a community organization provides motivation. Discussions within the student group help the students reflect on the experience. The group then analyzes what the real problem is and proceeds to designing a solution. When the design is discussed with the community organization, the cycle repeats. Students who are highly theoretical (Kolb’s assimilator learning style) may have difficulty with service learning.
Service learning in engineering was developed at Purdue University as the Engineering Projects in Community Service (EPICS) program (Coyle et al., 2006). Initially, the primary purpose was to have electrical engineering students learn professional skills including ethics, working on multidisciplinary teams, communication, working with non-engineer customers, and socialization into the local community. The program was quickly opened to students in all engineering and non-engineering disciplines. Students at all levels can be involved. Seniors in electrical engineering and in multidisciplinary engineering can use EPICS as their ABET approved major design experience. Seniors typically serve as team leaders. EPICS requires all teams to tackle real, ill-defined, open-ended problems and to take responsibility for finding a solution that satisfies the customer (the community organization). In other words, the students are asked to do engineering. The 2005 NAE Bernard M. Gordon Prize was awarded to Leah Jamieson, Ed Coyle, and Bill Oakes for the development of EPICS, Purdue’s pioneering engineering service-learning program.

EPICS teams are truly multidisciplinary and may include students from engineering, technology, science, liberal arts and other disciplines. Although students learn a bit about communicating with other disciplines, there is a tendency for a team to divide into two or more groups. For example, the liberal arts students may be given communication and secretarial roles while the engineers do design and calculation tasks (Heywood, 2005). The team will perform better if all students are integrated into the process. Determining ways to do this integration reoccurs for every new multidisciplinary team.

One of the authors (PCW) has had a ring-side seat to the EPICS program as the resident for eight years of an office next to the EPICS’ offices and as director of multidisciplinary engineering program. Multidisciplinary engineering has the highest percentage of students taking EPICS, and the director serves on the design review board for students taking EPICS as their capstone design course. My personal impressions are that about 30% of the students become totally involved in EPICS. These students take multiple EPICS classes, serve as a leader for at least two semesters, create a portfolio from their EPICS experiences, are offered jobs based on the EPICS experience, find their EPICS experience has prepared them well for work, and generally benefit greatly from EPICS. For these students EPICS is usually the highlight of their college career. There is also a middle group of about 60% of the students who benefit from EPICS, perhaps a bit more than from another 3-credit class, but EPICS does not have the major impact it does on the top 30%. However, EPICS is a worthwhile course for them. And then there is the approximately 5 to 10% of students who dislike EPICS, a few to the point of hating it. The students who end up disliking EPICS do not see how to apply real (theoretical) engineering to the messy problem and believe that the instructors are unfair for not providing them with a clearly defined route to the correct answer.

Teaching/administering a service learning program is hard work. Any dean or upper administrator who thinks that service learning will be an inexpensive way to offer engineering design courses is going to be very surprised. The program is always looking for new community projects, developing new teams to tackle the projects and recruiting new students to serve on the teams. When everything goes well—the team leader is in the top 30%, she is enthusiastic, has her team functioning well, and the team understands what the community organization needs—everyone is happy, it is smooth sailing, and being a service learning instructor is easy and fun. But when a team or, less often, the community organization becomes dysfunctional, the instructors need to try to salvage the students’ learning, the project, and the
relationship with the community organization. All the skills in working with teams discussed in this chapter and all the skills in advising (chapter 10) and understanding people (chapters 13 to 15) need to be used to try for an acceptable conclusion.

So why bother? For 90 to 95% of the students EPICS is a good class that the students benefit from and for 30% of the students EPICS is positively life-altering. Research (Bielefeldt et al., 2009) has shown that engineering students in service learning gain technical knowledge at the same rate as students in standard courses. However, there are much larger gains in nontechnical aspects of design such as working with nontechnical customers, increased social awareness, and increased professional and ethical responsibility. In addition, service learning attracts a more diverse population to engineering. Thus, EPICS is the type of course the Carnegie Foundation (Shepard et al., 2009) thinks is necessary to revitalize engineering education.

Although some schools that do not have formal service learning courses in engineering have extracurricular activities that allow students to become involved in service learning (e.g., Bluelab, 2014), service learning is not widely used in engineering education.

7.11. TINY CLASSES

Consider this scenario. You are walking down the hall, idly glancing in at the classes when you come to a classroom that is almost empty and the professor is lecturing to three (or six or eight) students. You realize that this is a graduate elective and you’ve seen the entire class. Unless the professor does not know of any alternatives, why would anyone lecture to a tiny class? To be honest, the first time we had a tiny class we did not know any better and spent most of the semester lecturing. But after that we learned. Use a method that really involves the students and provides a significant amount of personal attention.

One approach is to use a classical or modified Oxford tutorial. With three students you can meet individually with each student once or twice a week. Provide them with readings and have them tell you what they learned since the last meeting. Determine the right level to challenge each student and let the students move at their own pace. Since you are not preparing lectures, you could easily give six students an hour each week. If you have more than six students you can meet with the students in pairs. Have them work together during the week, but make them explain their progress one at a time so that they have individual accountability.

Although there is a significant amount of interaction with the students and the pairs can work as a cooperative group, the course is instructor-led. You structure the course, decide what needs to be covered, what the appropriate readings and problems are, how fast to proceed, what projects the students should do, how the students should be assessed, and so forth.

One option is to have each student select some of the readings every other week (Light, 2001). When a student chooses the weekly readings, that student is responsible for planning the discussion. This course then becomes partly instructor-led and partly student-led.

There is another alternative with a small group of graduate students that, for lack of a better term, I (PCW) called super PBL (Wankat, 1993, 2002). Have the students pick the problem to work on and structure the work. You can do this by having the students write a textbook chapter on an advanced topic. A textbook chapter is better for this type of course than a review paper because one needs to understand the material better to write a textbook chapter. A textbook needs objectives, examples, and homework assignments in addition to text. I gave
the student pairs a list of about 50 advanced separation processes they could choose to work on. The only rules were that the topic could *not* be closely related to their thesis research and it could not be a topic they had studied for a project in another course.

During the semester I gave three lecture/discussions: one on efficient analysis of the literature and efficient writing (see Chapter 2), one analyzing what makes a good textbook chapter, and one analyzing good and bad papers in the literature. A librarian gave two lectures on doing electronic literature searches including searches of the patent literature. To prevent procrastination the groups had to turn in short progress reports periodically, a detailed outline, a first draft, and a final draft that corrected any problems in the first draft. Most weeks I met with each group twice during the regularly scheduled class meetings. These meetings were also a check on procrastination since the students found it embarrassing to have nothing to talk about. Early in the semester I mainly made sure that each group had controlled their topic so that they could finish the chapter in one semester. Later in the term I checked that the groups were not missing anything obvious in their chapters, and gave pep talks when the students doubted their ability to complete the task. At the end of the semester I assessed the first drafts and provided feedback the next class period, and then graded the final papers.

One group’s textbook chapter was amazing and the other groups’ chapters were merely good. The students were somewhat disappointed that their chapters were not published in a book; however, the class made writing their theses considerably easier since they had already practiced many of the tasks required to write a good thesis.

An alternative procedure for drafts is likely to result in somewhat better work. Call the first draft the final draft, worth 100 points, and call the second draft a rewrites draft worth 50 points (Stearns, 2013). Students who receive an A on their final draft do not turn in a rewrites draft and automatically receive 50 points. Wikis (Section 8.6) would probably be very useful for group writing and revision of chapters.

In 40 years as a professor this is the only course I have ever taught where every student worked harder than I did. But, before you run off to teach a course like this, there are caveats. Since the professor gives a lot of the decision making and control to the students, the students will take the projects in unexpected directions, but still be within the constraints set by course topics. You need to decide if you are comfortable with this. Since you do not control topics, you need to be much more widely read within the subject area of the course than in a standard lecture course where you control the material. Expertise is necessary to determine if students are going off on an unimportant tangent and for calibrating your “BS meter” to determine when students are trying to get away with something. The quality of student-written chapters will be variable. Several years ago I reviewed a book written in this way by a class of first- and second-year undergraduates. The book was not publishable.

Tiny classes are a gift from the scheduling gods that you probably will not see very often. Do not waste the gift by lecturing.

### 7.12. MAKING THE CHANGE TO ACTIVE LEARNING WORK

Active learning works, but switching your entire course to active learning is not going to be easy. First, use some active learning in your lecture classes to acclimate the students and give yourself some experience and confidence in the procedures.
There is a learning curve. You will make mistakes. But you make mistakes in lecture also. The difference is you are comfortable in lecture and you don’t let the mistakes bother you. Most professors are not comfortable their first time teaching an active learning class. But they probably weren’t comfortable the first time they taught a lecture class either. If you can, find a mentor who is familiar with active learning. Watch the mentor teach a few times and talk to him or her on a regular basis.

Active learning works, but converting students who have spent the last three to four years sitting passively in lectures to active learners is not going to be easy. “Eighteen-year-old students have to be weaned away from instructor-led learning and information receiving” (Heywood, 2005). Many students prefer known teaching methods because the known is more secure. This is particularly true in core courses because the students often feel they have no alternative. Surprisingly, the B students will probably complain the most. The A students are usually confident they can learn despite how much you muck up the teaching. The C students have not thrived under the existing lecture system, and if you do even a modest sales pitch they will think it might help and certainly will not be worse. It’s the B students who believe they have something to lose if you switch to a new method.

Active learning works, but the shock of being forced to be responsible for their own learning will result in many students going through the stages of trauma and grief (Felder, 1995; Woods, 1994). The stages many students will exhibit are:

1. **Shock.** I can’t believe it. He’s going to stop teaching and test us based on what our group teaches us.
2. **Denial.** It’s not April Fool Day, but this must be his idea of a sick joke. He will return to lecturing shortly.
3. **Emotions.** #!%&. Give us a break. This is going to kill me. He’s not teaching this course next term is he? My father knows a state senator and we’ll complain to him. He can’t do this—this is a state school.
4. **Resistance and/or Withdrawal.** This is really dumb. I’m supposed to learn from my classmates and they don’t know #!%&. Well, he can flunk all of us.
5. **Surrender and Acceptance.** What am I supposed to do? The professor is trying the dumbest experiment ever, and I have to take this course.
6. **Struggle and Exploration.** How come Jack and Harry seem to be getting this stuff? Heck, Jack’s grades are always lower than mine. If he can learn it, so can I.
7. **Confidence Returns.** The team really surprised me today—we came up with a really cool design and the Prof. even said it would work.
8. **Integration and Success.** As each student gets it, they tend to move other students into stages 6 and 7 and the process becomes easier.

Active learning works, but at different times for different students and with different degrees of difficulty. You may be surprised by who jumps in and moves into steps 7 and 8 with almost no angst. Other students may get stuck in steps 3 or 4. Although active learning does not have to include group work, most of the currently popular methods do include group work. Strong introverts may protest and stay in stage 4 the entire semester.

Active learning works, and you can help it work by preparing the students for it by e-mailing them during registration if you can. Tell them in the e-mail and on the first day what the teaching/learning environment will be like and be sure your syllabus describes the
method also. Use the active learning method on the first day of class if you can—if not, be sure to use active learning the first week of the term. Explain what you will do, what they will do, and why. The why is because students learn more. 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). If the new method will help graduates find jobs, explain this also.

Since active learning works, students who have had a previous positive experience with active learning normally do not go through these eight stages. When you assign groups, spread out the experienced students into as many groups as possible. Experienced students will have already developed some of the essential teamwork and problem solving skills. Help the other students develop these skills with guidance during class and during office hours.

Active learning works and the more chutzpah you have, the faster it will be obvious that the method is working. The first time I (PCW) taught a mastery learning course, 85% of the students failed the second quiz. I acted as if this was normal and that I knew most of them would pass the first make-up quiz. Most buckled down and studied, and as a result passed the makeup. I helped by making the makeup a bit easier. From then on the students were more confident than I was that I knew what I was doing. I did this experiment in an elective course since professors are scrutinized less and the students are all volunteers. Volunteers will do things without much complaint that will cause students in a core course to storm the Bastille.

To help active learning work, remove as many obstacles as you can. For example, in a flipped class beta test the screencasts or videos and be sure they are ready in advance.

By mid-term you will be tired of complaints; however, it is time to ask for more. Conduct a mid-term evaluation from the students. Ask the students to tell you what is working for them, what is not working for them, and what you and the TAs can do to help them learn. Chances are the course is working better than you knew. A few noisy, disgruntled students can sound like the entire class is in revolt. You may have the silent majority on your side. Read through the evaluations and see if you can make any changes to remove irritations that are unnecessary for the success of active learning. I collate the comments and report the results back to the class along with my proposed actions to improve learning in the course. The evaluations and feedback to the students appear to help students who are stuck in stages 3 or 4 to get past these points.

There is good news. If these students take another active learning course most of them will not need to go through the same eight steps—they will just jump right in. Plus there is a carry-over effect to other cadres of students. If you teach this year’s juniors actively next year the juniors will have heard about the course and be more willing to participate (Koretsky and Brooks, 2012). Once active learning becomes part of the departmental culture, there will be little resistance.

### 7.13. CHAPTER COMMENTS

We’ve given you a smorgasbord of different methods that can be used either as part of basically a lecture class, as a break in a class, as the main teaching method instead of lecturing, or as the classroom part of a flipped class. All these methods try to involve the student with the content and work to make the student active, but these methods certainly do not exhaust the possibilities. With some creativity, you can develop new variations to involve your students.
Cooperative group and mastery techniques both clarify the need for clear learning objectives. Cooperative groups emphasize 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. These truths can be adopted in other teaching methods.

Introducing change in the classroom can be difficult. Professors cling to lecturing partially because it gives them control, minimizes preparation time, has little risk and is socially acceptable within their department. If giving up control of the class is difficult for you, try active learning methods, such as short informal groups interspersed in lectures, instructor-paced mastery learning, or guided design (see Section 9.2.6), that retain instructor control.

Faculty ignored Yale’s report in 1828 that active learning methods are better than lecture. Engineering faculty ignored the 1954 research that showed students learned more with mastery learning than they did with lecture. More recent research has confirmed both of these findings. An increasing number of engineering professors are using various active learning methods. Make one of your personal objectives the adoption of active learning in your teaching.

HOMEWORK

1. Choose a specific undergraduate engineering course that is normally taught using the lecture method. Determine how you can incorporate two of the teaching methods listed in the first objective in Section 7.1 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 an active learning method. Prepare a detailed script for two days of class.

REFERENCES


