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Teaching Engineering, Second Edition

Phillip C. Wankat
Purdue University

Frank S. Oreovicz
Purdue University

TEACHING ENGINEERING

SECOND EDITION

Phillip C. Wankat
Frank S. Oreovicz

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Preface to the Second Edition, 2015

Fundamental science and engineering concepts change slowly while technology changes rapidly. Methods for teaching engineering students follow the same rule—the fundamental concepts are just as true today as twenty-two years ago when *Teaching Engineering* was first published. In many cases, such as cooperative learning and active learning, there are stronger research bases, proving that students learn more with these methods than when they are passive observers in a lecture class, but the basic how-to-teach procedures have not changed. The applications of technology to teaching have changed rapidly, as Chapter 8, "Teaching with Technology," became out-of date within a few years. The only other part of *Teaching Engineering* that has not withstood the test of twenty-two years is the section on ABET accreditation. ABET's development of EC 2000 in the late 1990s changed accreditation significantly.

In this second edition we have brought all of the chapters up to date and added significant amounts of material in the following chapters and appendices:

- Chapter 1: new section 1.6 on the effectiveness of teaching courses and workshops and 1.7 on the characteristics of great teachers.
- Chapter 4: Section 4.7 on ABET is entirely revised, new Section 4.8, Case study of curriculum development, and new appendix A4: Sample rubrics for ABET professional outcomes.
- Chapter 5: New section 5.4.2 on solving novel problems
- Chapter 6: New section 6.7.4 on clickers.
- Chapter 7: New sections 7.2 on flipped classes, 7.5 on problem based learning, 7.10 on service learning, 7.11 on teaching tiny classes, and 7.12 on making the change to active learning work. Research results that support the use of active learning have been added.
- Chapter 8: New sections 8.5 on simulations and games and 8.6 on YouTube and wikis. All material is updated.
- Chapter 9: New sections on design competitions (9.2.8) and remote laboratories (9.3.5).
- Chapter 10: New sections 10.4.3 on FERPA and 10.4.4 on learning communities.
- Chapter 11: New section 11.7 on grade scales and new appendix showing grade calculations for different grading schemes.
- Chapter 15: New sections 15.3.3 and 15.3.4 on learning styles and 15.5 on *How People Learn*.
- Chapter 16: New section 16.6 on teaching improvement.
- Chapter 17: New section 17.2 on how faculty spend their time.
- New appendix B: assignment list, course schedule and syllabus for our course, Educational Methods for Engineers, at Purdue.

We would like to thank Charles Watkinson, the former director of the Purdue University Press and former head of Scholarly Publishing Services of the Purdue University Libraries for sponsoring the second edition, and Katherine Purple, managing editor of the Purdue University Press, for designing the cover and assistance in publishing the book. The assistance of Dr. Susan Montgomery at the University of Michigan in reviewing the second edition before it was published was invaluable. The further proofreading of the supposedly finished book by Professor Michael Loui provided polish to the final product. Readers who wish to correspond with the authors about teaching and learning questions can send e-mail to wankat@purdue.edu.

Finally, we dedicate this book to our children—Charles and Jennifer, and John (and Patrick) and Mary-Kate; and our wives, Dot and Kathryn, who have always been continually supportive.

Phil Wankat and Frank Oreovicz
West Lafayette, Indiana
June 2014

Preface to the First Edition, 1993

With his characteristic cleverness, George Bernard Shaw armed several generations of cynics with his statement "Those who can, do; those who can't, teach." But in today's world, engineering professors have to be able to do engineering *and* to teach engineering. How they prepare for this task is the subject of this book, which grew out of our conviction that new faculty are entering the university well prepared and well mentored in doing research, but almost totally at sea when it comes to the day-to-day requirements of teaching. At best, graduate students obtain only a second-hand knowledge of teaching, rarely having the opportunity to conduct an entire class for an extended period of time. If their role models are good or, better yet, master teachers, then some of the luster may wear off and they may gain valuable exposure to the craft. More often than not, the opposite occurs. An individual with a desire to teach has to rely on his or her own interest in teaching, and later discovers, with the mounting pressure of producing publications and research, that he or she can give only minimal attention to the classroom. This is a risky way to ensure the future of our discipline.

In 1983 we developed and taught for the first time a graduate course, Educational Methods for Engineers, geared toward PhD candidates who were interested in an academic career. Our sources came from a variety of disciplines, journals, and books because we immediately noticed that no textbook was available which focused solely on engineering. Classic texts such as Highet's and McKeachie's became starting points and we scoured the literature for what was available in engineering. With a grant from the National Science Foundation in 1990 we expanded the course to include all of engineering, conducted a summer workshop, and began this book much earlier than we otherwise could have. Although the writing of this book was supported by NSF, all of the views in this book are the authors' and do not represent the views of either the National Science Foundation or Purdue University.

Many people have helped us, often unknowingly, in developing the ideas presented in this book. The writings and lectures of the following engineering professors have helped to shape our thinking: Richard Culver, Raymond Fahien, Richard Felder, Scott Fogler, Gordon Flammer, Lee Harrisberger, Billy Koen, Richard Noble, Helen Plants, John Sears, Bill Schowalter, Dendy Sloan, Karl Smith, Jim Stice, Charles Wales, Patricia Whiting, Don Woods and Charles Yokomoto.

At Purdue, Ron Andres suggested the partnership of W & O; others influential include Ron Barile, Kent Davis, Alden Emery, John Feldhusen, Dick Hackney, Neal Houze, Lowell Koppel, John Lindenlaub, Dick McDowell, Dave Meyer, Cheryl Oreovicz, Sam Postlethwait, Bob Squires, and Henry Yang, plus many other faculty members. Our students in classes and workshops tested the manuscript, and their comments have been extremely helpful. Professor John Wiest audited the entire class and his discussion and comments helped to mold this

book. Professor Felder's critique of the book led us to reorganize the order of presentation. Professor Phil Swain was extremely helpful in polishing Chapter 8. Without question, the work of Mary McCaulley in extending and explicating the ideas of Katherine Briggs and Isabel Briggs-Myers formed our thinking on psychological type and its relevance to engineering education. Catherine Fitzgerald and John DiTiberio provided first-hand exposure to Type theory in action.

In the early formatting stages, Margaret Hunt provided invaluable assistance; Stephen Carlin drew the final figures and did the final formatting of the text. Betty Delgass provided the index as well as helpful suggestions and comments on both style and substance. We also wish to acknowledge the careful and helpful close reading by the McGraw-Hill copy editors, as well as the patient guidance through the publishing process provided by editors B. J. Clark and John Morriss. Through it all, our secretaries, Karen Parsons and Paula Pfaff, tirelessly dealt with two authors who often made changes independently.

Finally, we dedicate this book to our families in appreciation for their patience and support: To our wives, Dot and Sherry, for listening to our complaints; and to our children—Charles and Jennifer, and John and Mary-Kate: With their future in mind we wrote this book.

CHAPTER 1

INTRODUCTION: TEACHING ENGINEERING

It is possible to learn how to teach well. We want to help new professors get started toward effective, efficient teaching so that they can avoid the "new professor horror show" in the first class they teach. By exposing them to a variety of theories and methods, we want to open the door for their growth as educators. Since one goal is immediate and the second is long-term, we have included both immediate how-to procedures and more theoretical or philosophical sections. Written mainly for PhD students and professors in all areas of engineering, the book may be used as a text for a graduate-level class or by professionals who wish to read it on their own. Most of this book will also be useful to teachers in other disciplines. Teaching is a complex human activity, so it's impossible to develop a formula that guarantees excellence. But by becoming more efficient, professors can learn to be good teachers and end up with more time to provide personal attention to students.

1.1. SUMMARY AND OBJECTIVES

After reading this chapter, you should be able to:

- Discuss the goals of this book.
- Answer the comments of critics.
- Explain the two-dimensional model of teaching.
- Discuss some of the values which underlie your ideals of teaching.
- Explain some applications of learning principles to engineering education.

1.2. WHY TEACH TEACHING NOW?

Most engineering professors have never had a formal course in education, and some will produce a variety of rationalizations why such a course is unnecessary:

1. *I didn't need a teaching course*. Just because someone did not need a teaching course does not logically imply that he or she would not have benefited from one. And times have changed. In the past, young assistant professors received on-the-job training in how to teach. New assistant professors were mentored in teaching and taught several classes a semester. Now, mentoring is in research, and an assistant professor in engineering at a research university may teach only one course a semester. In the past the major topic of discussion with older professors was teaching; now it is research and grantsmanship. Thus, formal training in teaching methods is now much more important.

The problems facing engineering education have also changed. In 2009 (the most recent year for which data is available) 468,139 undergraduate engineering students were enrolled, which is 2.63% of the total of 17,778,741 undergraduates enrolled at all US institutions (NSF, 2013). If we look at only US citizens and permanent residents there were 440,791 undergraduates in engineering, which is 2.53% of the 17,404,882 total enrollment. The number of traditional new engineering students—white American male eighteen-year olds—is expected to drop slowly for at least the next 15 years (NSF, 2013). The 2010 population data in 5-year cohorts illustrates a slow decrease in numbers after the 15–19 bulge (Table 1-1). In 2014 the students in the 2010 15–19 cohort are currently in college. Cohort data by race and ethnicity is shown in Table 1-2. Since the cohorts do not match, the ratio calculations in Table 1-2 estimate the numbers for matching 7-year cohorts. The only groups that will have larger college age cohorts in the next 15 years are Hispanic or Latino, two or more races, and other races. Since the percentage of females does not change much, white male cohorts decrease at the same rate the white cohorts decrease. As the under-five cohort was 50.8% white in 2010 and the percentage of white babies continues to decrease, there will not be an increase in the percentage of traditional white male engineering students in the foreseeable future.

First, there is a moral imperative for reaching out to nontraditional students, including women, underrepresented minorities, veterans, low socioeconomic status, first generation college students, students of varying religions, and LGBTQ (lesbian, gay, bisexual, transgender, questioning) students. The 2011 enrollment of undergraduate students in engineering by race/ethnicity and by gender is given in Table 1-3. If all students had equal opportunity to study engineering, then the percentages of each group in engineering would be close to the corresponding percentages in the entire population. Clearly there are disparities. For example, if black or African American students studied engineering at the same percentage as the overall population there would be 2.4 times as many black or African American students as there are currently (assuming no change in the number of all other students. The largest disparity is in the number of female

Table 1-1. 2010 Population of United States (NSF, 2013)

Cohort	Number	% Female
Total	308,746,000	50.8
<5	20,201,000	48.9
5–9	20,349,000	48.9
10–14	20,677,000	48.8
15–19	22,040,000	48.7
20–24	21,586,000	49.0

Table 1-2. 2010 US Population by Race/Ethnicity (NSF, 2013)

Race/Ethnicity	Total	<5	Ratio 1	5–17	Ratio 2	18–24
All	308,746	20,201	28,281	53,980	29,066	30,672
White	196,818	10,254	14,356	29,462	15,864	17,547
Asian	14,465	875	1,225	2,301	1,239	1,491
Black or African American	37,686	2,754	3,856	7,608	4,097	4,373
Hispanic or Latino	50,478	5,114	7,160	12,016	6,470	6,154
American Indian or Alaska native	2,247	175	245	472	254	262
Native Hawaiian/Pacific Islander	482	38	53	98	53	64
Two or more, not Hispanic	5,966	924	1,294	1,865	1,004	707
Other race, not Hispanic	604	67	94	156	84	73

Note: Numbers in thousands. Ratio 1 equals the number in the <5 cohort adjusted to 7 years: (# in group <5) × (7/5); ratio 2 equals the number in 5–17 cohort adjusted to 7 years: (# in 5–17 group) × (7/13).

Table 1-3. 2011 Undergraduate Enrollment of US Citizens and Permanent Residents in Engineering Programs by Race/ethnicity and Gender. Total US and permanent resident undergraduate engineering students was 439,827 which were 81.446% male and 18.554% female. The first row of data gives the % each race/ethnicity is of total number of engineering students. The 2nd row of data gives the % of each race/ethnicity in the total US population (2010 data from Table 1-2).Third and 4th rows are the % of each race/ethnicity that are male and female, respectively. Data is based on Table 2-10 in NSF (2013).

	White	Asian	Black or African American	Hispanic or Latino	Native American	Pacific Islander	> 1 Race/ Ethnicity
% All US UG Engr. Students	69.696	8.643	5.508	10.574	0.530	0.225	1.897
% all US pop. (Table 1-2)	63.745	4.685	12.206	16.349	0.728	0.156	1.932
% Male	83.0	78.3	75.4	79.1	77.7	79.7	76.5
%Female	17.0	21.7	24.6	20.9	22.3	20.3	23.5

engineering students since parity with the overall population would require increasing the number of female engineering students by a factor of 4.2 (assuming no change in the number of male students). Of course, many students belong to two or more of these nontraditional groups.

Second, to remain internationally competitive, we must recruit, teach, and retain nontraditional students. They often have different experiences studying engineering (Table 1-4) and will often learn more with active learning methods than with lecture.

Table 1-4. Common Experiences of Non-Traditional Engineering Students (Modified from Susan Montgomery Lecture Material)

Women	• Faculty tend to interact more with men • Men interrupt more, women more hesitant • Women display a lack of confidence • Women cite lack of faculty contact • Women hide academic abilities • Women prefer a cooperative environment • Women feel sexualized
Under-represented Minorities	• Low faculty and peer expectations • Faculty don't care about us . . . or reach out • Faculty don't understand we are different • Faculty single us out as "spokesperson" for our group • Curriculum and faculty interactions exclude us • Faculty seem uncomfortable or cautious with us • Faculty sometimes take overt stances in class against diversity issues and initiatives • Out of class interactions with faculty are minimal and difficult
Veterans	• Alienation and isolation • Family adjustments • Loss of structure • Balancing multiple responsibilities • Academic concerns returning to school • Health and disability difficulties
First Generation College	• Embarrassment and guilt • Desire a sense of belonging • Overwhelmed by workload • Self-doubts about ability • Family pressure to succeed • Identity confusion • Financial difficulties • More familiar with oral than written communication
Low Socioeconomic Status	• Financial difficulties • Family pressure to drop out and help support family • Limited access to resources • Affordability of college, books, housing, etc. • Need to work while attending college
Varying Religions	• Lack of recognition of their religious holidays • Cultural differences • Differences in dress • Discrimination against some religions
LGBTQ (Lesbian, Gay, Bisexual, Transgender, or Questioning)	• Mental health concerns • Discrimination • Housing concerns • Questions of trust

Unfortunately, women and underrepresented minority students see few women or underrepresented minority faculty members. In 2012, 14% (3515) of the 25,004 tenure-track engineering faculty in the United States were female (Berry, Cox, & Main, 2014). Although the percentage of female faculty in engineering has increased significantly since the 9% recorded in 2001, the percentage remains disappointingly low compared to the total population (Table 1: 50.8% female). Only 31.3% of the women were tenured full professors compared to 52.5% of the men (Berry et al., 2014). Underrepresented minority engineering faculty members have increased (black or African American from 2 to 3% and Hispanic or Latino from 3 to 4%), but from very low bases. African American female engineering faculty was 4% of all female engineering faculty in 2012. Approximately one-third of the African American female engineering faculty worked at one of the 12 Historically Black Colleges and Universities with an engineering program (Berry et al., 2014).

How do we encourage enough US citizens, particularly women and underrepresented minorities, to earn a PhD and then become educators? Many graduate students see the workloads of assistant professors as oppressive and do not want the tenure decision hanging over their heads. A course on efficient, effective teaching reduces the trauma of starting an academic career and will help these students to see the joys of teaching.

2. *I learned how to teach by watching my teachers*. Highet (1976), in simpler times, argued that a course on education during graduate study is not needed since students can learn by watching good and bad teachers. What if the teachers you watched were bad teachers? Even if you had good teachers, observing at best gives you a limited repertoire and does not provide for necessary practice. Observing also does not help you incorporate new educational technology into the classroom unless you have had the rare opportunity to take a course from one of the pioneers in these areas.

3. *Good teachers are born and not made*. Some of the characteristics of good teachers may well be inborn and not made, but the same can be said for engineers. We expect engineers to undergo rigorous training to become proficient, so it is logical to require similar rigorous training in the teaching methods of engineering professors. Experience in teaching engineering students how to teach shows that everyone can improve her or his teaching (see Section 1.5). Even those born with an innate affinity for teaching or research can improve by study and practice. Finally, in its extreme, this argument removes all responsibility and all possibility for change from an individual.

4. *Teaching is unimportant*. Teaching is very important to students, parents, alumni, accreditation boards, and state legislatures. Unfortunately, at many universities research is more important than teaching in the faculty promotion process. At undergraduate-focused institutions teaching is very important and faculty promotion and tenure depend heavily on teaching ability. An efficient teacher can do a good job teaching in the same or less time an inefficient teacher spends doing a poor job. Although sometimes less important for promotion, teaching is included in the faculty promotion process at all institutions. New professors who study educational methods will be better prepared to teach, will spend less time teaching, and will have more time to develop their research during their first years in academia.

5. *Teaching courses have not improved the teaching in high schools and grade schools*. There is a general trend toward reducing the number of courses in pedagogy and increasing the number of content courses for both grade school and high school teachers. However,

there is no trend toward zero courses or no practice in how to teach. The optimum number of courses in teaching methods undoubtedly lies between the large number required of elementary school teachers and the zero number taken by most engineering professors.

6. *Engineers need more technical courses*. The demand for more technical courses is frequently heard at the undergraduate level. At the graduate level some of the most prestigious US universities require the fewest number of courses. Thus, arguments that graduate students must cover more technical content lack conviction. Courses on teaching can be very challenging and can open up entirely new vistas to the student. Graduates who went into industry or government reported the communication and psychology portions of the course were very useful (Wankat and Oreovicz, 2005).

7. *If I am a good researcher, I will automatically be a good teacher*. Unfortunately, there is almost no correlation between effective teaching and effective research (see Section 17.4 for a detailed discussion). Frequently heard comments to the contrary are anecdotal. This is not a statement that engineering professors should not do research. Ideally, they should strive to do both teaching and research well, and they should be trained for both.

8. *Even if a teaching course might be a good idea, none is available*. There are courses in teaching in engineering colleges (e.g., Heath et al., 2013; Stice, 1991; Wankat and Oreovicz, 1984, 2005). At the University of Texas at Austin the teaching course has been offered since 1972 (Stice, 1991). The Ohio State course is online and students are paired with a faculty mentor (Heath et al., 2013). In addition, the University of Delaware, University of Alberta and Northwestern University have similar teaching fellow programs that provide a supervised practicum in teaching engineering (Russell et al., 2014). Many universities have focused their efforts into campus-wide courses often as part of a Preparing Future Faculty program. Many, if not most, universities offer teaching workshops either before the semester starts (e.g., Felder et al., 1989) or during the semester (e.g., Wentzel, 1987). Professors who missed a course in graduate school can sign up for the American Society for Engineering Education (ASEE) National Effective Teaching Institute (NETI) (e.g., Felder and Brent, 2009).

9. *If I need to adopt a new teaching method during my career, I will do it on my own*. Adopting a totally new teaching method on your own is possible but quite difficult. McCrickerd (2012) notes that one important but usually hidden reason professors hesitate to improve their teaching is fear of failure. It is much easier to try new methods as part of a course or workshop where there is a mentor to provide assistance and other students to provide support.

A large number of reports have called for training engineering professors how to teach. Both the Mann and the Wickenden reports of SPEE (the precursor of ASEE) call for teacher training (Kraybill, 1969). The ASEE Grinter report (Grinter, 1955) states, "It is essential that those selected to teach be trained properly for this function." The ASEE Quality of Engineering Education Project concluded, "All persons preparing to teach engineering (the pre-tenure years) should be required to include in their preparation studies related to the practice of teaching" (ASEE, 1985, p. 156). The Institution of Engineers Australia (1996, p. 61) recommended engineering schools develop policies to "ensure that staff undertake formal courses in learning and teaching." Simon (1998, p. 343) noted that athletic coaches in college are trained in coaching, which is a form of teaching, and then stated "we should ask seriously whether we, too, should not be paying explicit attention to the techniques of learning and teaching." Wankat (2002) recommended that institutions hiring assistant professors should require candidates to have taken an education course or to attend an extensive teaching workshop. The 2009 ASEE phase I report (Jamieson and Lohmann, 2009, p. 11) stated, "It is reasonable to expect students aspiring to faculty positions to know something about pedagogy and how people learn when they begin their academic careers." This sentence is repeated in the ASEE final report *Innovation with Impact* (Jamieson and Lohmann, 2012, p. 19), and the first recommendation of the report is "Value and expect career-long professional development in teaching, learning, and education innovation for engineering faculty and administrators, beginning with pre-career preparation for future faculty" (Jamieson and Lohmann, 2012, p. 46). Wankat (2013) concluded that training professors how to teach was necessary to successfully reform engineering education.

There is one additional very good reason: Teaching when you don't know how may be considered unethical! Canon 2 of the engineering code of ethics states, "Engineers shall perform services only in the areas of their competence" (see Table 12-1). Since teaching is a professional service, teaching when one is not competent is probably unethical.

1.3. THE COMPONENTS OF GOOD TEACHING

A good teacher is characterized as stimulating, clear, well-organized, warm, approachable, prepared, helpful, enthusiastic, fair, and so forth. Lowman (1995) synthesized the research on classroom dynamics, student learning, and teaching to develop a "two-dimensional model" of good teaching. The more important dimension is intellectual excitement, which includes content and performance. Since most engineering professors think content is most important, making this dimension most important agrees with common wisdom in the profession. Included in intellectual excitement are organization and clarity of presentation of up-to-date material. Since a dull performance can decrease the excitement of the most interesting material, this dimension includes performance characteristics. For great performances professors need to have energy, display enthusiasm, show love of the material, use clear language and clear pronunciation, and engage the students so that they are immersed in the material.

Lowman's second dimension is interpersonal rapport. Professors develop rapport by showing an interest in students as individuals. In addition to knowing every student's name, does the professor know something about each one? Encourage them and allow for independent thought even though they may disagree with the professor? Make time for questions both in and out of class? Students consistently include this dimension in their ratings of teachers (see Section 16.4.2). At times the content and rapport sides of teaching will conflict with each other.

How do these two dimensions interact? The complete model is shown in Table 1-5. Lowman (1995) divides intellectual development into high (extremely clear and exciting), medium (clear and interesting), and low (vague and dull). He divides the interpersonal rapport dimension into high (warm, open, predictable, and highly student-oriented), medium (relatively warm, approachable, democratic, and predictable), and low (cold, distant, highly controlling, unpredictable). To interpersonal rapport we have added a fourth level below low—punishing (attacking, sarcastic, disdainful, controlling, and unpredictable)—since we have observed professors in this category.

The numbering system in Table 1-5 indicates that professors improve their teaching much more quickly by increasing their intellectual excitement than by developing greater rapport with students. A professor who is high in interpersonal rapport and low in intellectual excite-

Table 1-5. Two-Dimensional Model of Teaching (Lowman, 1995)

Intellectual Excitement	Interpersonal Rapport: Punishing	Low	Moderate	High
High	6'. Intellectual Attacker	6. Intellectual Authority	8. Masterful Lecturer	9. Complete Master
Moderate	3'. Adequate Attacker	3. Adequate	5. Competent	7. Masterful Facilitator
Low	1'. Inadequate Attacker	1. Inadequate	2. Marginal	4. “Warm fuzzy”

ment (position 4) will be considered a poorer teacher than one who is high in intellectual excitement and low in interpersonal rapport (position 6). Because their strengths are very different, these two will excel in very different types of classes. The professor in position 4 will do best with a small class with a great deal of student participation, whereas the professor in position 6 will do best in large lecture classes. Our impression is most engineering professors are in the broad moderate level of intellectual excitement and are at all levels of interpersonal rapport. The difference between these teachers and those at the high level of intellectual excitement is that the latter either consciously or unconsciously pay more attention to the performance aspects of teaching. Fortunately, all engineering professors can improve their teaching in both dimensions, and position 5 (competent) is accessible to all. Although becoming a complete master is a laudable goal to aim for, teachers who have attained this level are rare.

Hanna and McGill (1985) contend that the affective aspects of teaching are more important than method. Affective components which appear to be critical for effective teaching include:

- Valuing learning
- A student-centered orientation
- A belief that students can learn
- A need to help students learn

These affective components are included in the model in Table 1-5. High intellectual excitement is impossible without valuing the learning of content and a need to present the material in a form that aids learning. High interpersonal rapport requires a student-centered orientation and a belief that students can learn.

A few comments about the punishing level of interpersonal rapport are in order. Since most students will fear such a professor, they will do the course assignments and learn the material if they remain in the course and aren't immobilized by fear. However, even those who do well will dislike the material. In our opinion and in the opinion of the American Association of University Professors (see Table 17-6), this punishing behavior is unprofessional. The only justification is to train students for a punishing environment such as that confronted by boxers, POWs, sports referees, and trial lawyers. Professors who stop attacking students immediately move into the level of low interpersonal rapport and receive higher student ratings.

One can add a number of additional components to the definition of good teaching. Wankat and Oreovicz (1998) added:

- High ratio of student learning to student time
- High ratio of student learning to instructor time

The first is student efficiency while the second is instructor efficiency, which makes the teaching sustainable. Students appreciate an efficient instructor. There is a high correlation between the fraction of their preparation time that students considered to be valuable and the student ratings of the instructor (Theall and Franklin, 1999).

1.4. PHILOSOPHICAL APPROACH

Teaching is an important activity of engineering professors, both in regard to content and in relation to students. New professors are usually superbly trained in content, but often have very little idea of how students learn. Our (revolutionary) hypothesis: Young professors will do a better job teaching initially if they receive education and practice in teaching while they are graduate students or when they first start out as assistant professors. They will be more efficient the first few years and will have time for other activities.

The teaching methods covered here go beyond the standard lecture format, although it too is covered. Unfortunately, for too many teachers teaching is lecturing. To broaden the reader's repertoire of teaching techniques, we include other teaching methods. Because advising and tutoring are closely tied to teaching, we also include these one-to-one activities. We also cover methods for teaching students to become good problem solvers and to learn how to learn. Since engineering professors must be involved in many other activities in addition to teaching, we emphasize both effectiveness and efficiency. We believe people want to learn. Therefore, we search for ways to stop demotivating students while realizing that a few discipline problems always exist.

Engineering professors invariably serve as models of proper behavior. Thus, an engineering professor should be a good engineer both technically and ethically, not using his or her position to persecute or take advantage of students. We agree with Highet (1976, p. 79) that in general students are likely to be immature and that "our chief duty is not to scorn them for this inability to comprehend, but to help them in overcoming their weakness." A well-developed sense of fairness is almost uniformly appreciated by students.

1.5. WHAT WORKS: A COMPENDIUM OF LEARNING PRINCIPLES

Throughout this book we will base teaching methods on known learning principles. Many comments on what works in teaching are scattered throughout. In this section we will list many of the methods that are known to work. The ideas in this section are based on Chapters 13 to 15, papers by Carberry and Ohland (2012); Chickering and Gamson (1987); Keeley, Smith, and Buskist (2006); Ripley (2010); and Roksa and Arum (2011); books by Farr (2010), Lang (2013), Lowman (1995), and Svinicki and McKeachie (2014); and the government brochure *What Works* (1986).

1. Guide the learner. Be sure that students know the objectives. Tell them what will be next. Provide organization and structure appropriate for their developmental level.
2. Develop a structured hierarchy of content. Some organization in the material should be clear, but there should be opportunities for the student to do some structuring. Content needs to include concepts, applications, and problem solving.

3. Use images and visual learning. Most people prefer visual learning and have better retention when this mode is used. Encourage students to generate their own visual learning aids.
4. Ensure that the student is active. Students must actively grapple with the material. This can be done internally or externally by writing or speaking.
5. Require practice. Learning complex concepts, tasks, or problem solving requires a chance to practice in a nonthreatening environment. Some repetition is required to become quick and accurate at tasks. Most students and faculty underestimate the amount of practice needed to learn new skills (Ambrose et al., 2010).
6. Check for understanding frequently. Question, listen, observe.
7. Provide feedback. Feedback should be prompt and, if at all possible, positive. Reward works much better than punishment. Particularly in communication, in addition to telling what is wrong, give some direction on how to do it correctly. Students need a second chance to practice after feedback in order to benefit fully from it.
8. Communicate your expectations that students will behave professionally , and professors should model professional behavior at all times. Engineering students are preparing for professional careers. They should start behaving professionally as first year students.
9. Have positive expectations of students. Positive expectations by the professor and respect from the professor are highly motivating. Students learn more from faculty who have high expectations. This important principle cannot be learned as a "method." Master teachers truly believe that their students are capable of great things.
10. Provide means for students to be challenged yet successful. Be sure students have the proper background. Provide sufficient time and tasks so that everyone can be successful but be sure that there is a challenge for everyone. Success is very motivating. The combination of items 9 and 10 can be stated succinctly. "I am going to challenge you," and "you are capable of meeting that challenge" (Lang, 2013, p. 157).
11. Individualize the teaching style. Use a variety of teaching styles and learning exercises so that each student can use his or her favorite style and so that each student becomes more proficient at all styles.
12. Make the class more cooperative. Use cooperative group exercises. Stop grading on a curve and either use mastery learning or grade against an absolute standard.
13. Ask thought-provoking questions. Thought-provoking questions do not have to have answers. Questions without answers can be particularly motivating for more mature students.
14. Be enthusiastic and demonstrate the joy of learning. Emphasize learning instead of grades. Enthusiasm is motivating and will help students enjoy the class.
15. Encourage students to teach other students. Students who teach others learn more themselves and the students they teach learn more. Students who tutor develop a sense of accomplishment and confidence in their ability.
16. Care about what you are doing. The professor who puts teaching "on automatic" cannot do an outstanding job.
17. Track student performance. Share the results with students. Students can make informed decisions about study if they know how they are doing in class.
18. Develop efficient routines for transitions, disseminating materials, collecting assignments, and so forth. Efficiency at these tasks leaves more time for student learning.

19. If possible, separate teaching from evaluation. If a different person does the evaluation, the teacher can become a coach and ally whose goal is to help the student learn.

These ideas can be stated succinctly: *engaged students learn* (Astin, 1993).

1.6. EFFECTIVENESS OF TEACHING COURSES AND WORKSHOPS

Extensive teaching workshops and courses improve teaching. The organizers of engineering teaching workshops at West Point (Conley et al., 2000) found that former students believed that they had improved because of the intensive one-week summer workshop. When asked, "Has your teaching improved as a result of attending this course?" 90% answered yes. The first edition of this book was used as the textbook. Brawner et al. (2002) found a self-reported increase in use of active learning methods by attendees of teaching workshops. The effectiveness of the American Society for Engineering Education (ASEE) National Effective Teaching Workshop (NETI) was studied by sending surveys to attendees from 1993 to 2006 (Felder and Brent, 2009). They found that 67% of the respondents reported an increase in teaching

Table 1-6. Survey Results of How to Teach Course (Wankat and Oreovicz, 2005)

Scale for questions 2 and 5: Negative = 1, Slightly Negative = 2, Neutral or No effect = 3, Slightly positive = 4, and Positive = 5. n = number of responses
Q. 2. Impact of the How-to-Teach course during job search for academic position? Score: 4.55, n = 25
Comments: "Writing the teaching statement and knowing what to expect as a professor has helped tremendously."
"It never came up in my interview. I assumed everyone had a course like this. Little did I know, that I was ahead of the curve on this."
Q. 5. "Impact of course on your academic career? Score 4.80, n = 17
Comments: "Improved my delivery skills on university lectures and training offerings to industry."
"Gave me a foundation on which to build a research program and continue to develop as a teacher."
Scale for question 3: Harmful = 1; Slightly harmful = 2; Neutral = 3; Slightly helpful = 4; Helpful = 5.
Q. 3. Effect of course on your first 2 years or less as an assistant professor. Score: 4.90 n = 17
Comments: "It was *immensely* helpful. I feel that I was very well prepared for what I would face."
"Made teaching a relatively easy task, which freed my time for research."
Scale for question 8: Strongly not recommend = 1; Not Recommend = 2; Neutral = 3; Recommend = 4; Strongly recommend = 5.
Q. 8. "Would you recommend a similar course to PhD students planning academic careers?" Score: 4.90, n = 42
Comments: "Should be a *required* course."
"The belief that the possession of a PhD gives you some innate ability to teach is ridiculous."
"Strongly recommended for those seeking positions at a teaching institution."

ratings, 29% reported no change, and "fewer than 6% reported a drop." (The sum does not add to 100% in the original paper.) They add "Also, inspection of individual responses shows that many who reported negative or negligible changes in their ratings had high ratings to begin with, so there was nowhere to go but down." This comment points to a problem with voluntary workshops: excellent teachers attend, and professors who would probably benefit the most from attending often do not. Walczyk et al. (2007) showed that a single, three-credit course for professors in science is sufficient to result in significant increases in teaching effectiveness, and the increase in effectiveness was retained several years later.

Wankat and Oreovicz (2005) conducted a longitudinal study of alumni from their 3-credit graduate course, "Educational Methods in Engineering." They received 42 useful responses (40%). Although a 40% response rate is low for a valid analysis (Felder and Brent, 2009), the authors analyzed the results. The primary research hypothesis was: "The course on educational methods would have a significant impact on graduates who followed academic careers." Impact included having an easier time finding a position, becoming a better teacher as shown by student ratings, and faster start-up as an assistant professor. Survey results from the questions focused on academic careers are summarized in Table 1-6. Based on these responses the course was considered very valuable for graduates who chose academic careers. A survey of teachers of similar courses indicated that these results should generalize to other how-to-teach courses.

Supervised teaching internships, which are also effective, can be organized several different ways. First, they can be modeled after formal programs in education and psychology. In this model the students sign up for a supervision "course" with a professor who supervises four to six students. Second, in Preparing Future Faculty (PFF) programs interns serve at another institution, such as a community college, working with a professor at that institution (Lewanowski and Purdy, 2001). Third, professors can formally (Baber et al., 2004; Russell et al., 2014) or informally (Sherwood et al., 1997) share a course with a selected graduate student. The professor attends class when the graduate student teaches and provides feedback. This model could be employed at any university, and since it is less structured, can be adapted to unique circumstances.

1.7. CHARACTERISTICS OF GREAT TEACHERS

We do not focus on creating great teachers because being great requires characteristics that are very difficult to teach. However, professors who are already good teachers often want to know what separates the great teachers from the merely good.

Teach for America asked: What differentiated the great teachers from the good ones? Over a number of years Steven Farr studied this question and developed the following list of six characteristics (Farr, 2010; Ripley, 2010):

1. Set big goals for students. Since few students will go beyond the goals that are set, modest goals lead to, at best, modest results. With big goals even the students who do not reach their goals will probably perform well. However, the teacher has to believe that the students can meet their goals.
2. Invest in students and their families. Involve students and family in the process of learning.
3. Plan purposely. Start with the desired outcome and plan backwards to the actions necessary to get the students to this outcome.

4. Execute effectively. Maintain focus on student learning. All other secondary goals should be handled as routinely and efficiently as possible.
5. Continuously increase effectiveness. Keep changing teaching methods with the goal of always getting better. “Good enough” is not good enough to become great.
6. Work relentlessly to reach goals. Refuse to let difficulties stop the students from learning and reaching their goals. Every institution has disadvantages, policies, and personalities that can be used as reasons for not doing better. Find a way around these difficulties.

Although developed for grade, middle school and high school teachers, these characteristics, with the exception of involving families in item 2, all apply to college teaching. Items 2, 3, and 4 can be taught in a course and are covered in this book. The What Works list in Section 1.4 will satisfy these three items. Unfortunately, we do not know how to teach instructors to *believe* that their students can meet big goals. We also do not know how to teach instructors to never be satisfied—and we doubt we should even try. Finally, we do not know how to instill the relentless drive and resilience that will allow a teacher to overcome all obstacles.

Bain (2004), Barrett (2012), Highet (1976), and Stice (1998) consider other characteristics of great teachers and distill additional lessons that may help teachers become better.

1.8. CHAPTER COMMENTS

At the end of each chapter we will step aside and look philosophically at the chapter. These “metacomments” allow us to look at teaching from a viewpoint that is outside or above the teacher. In class we use metadiscussion to discuss what has happened in class. Section 1.1, Summary and Objectives, gives readers an advance idea of what will be covered in the chapter. Advance organizers are particularly useful for readers who prefer a global learning style (see Section 15.3.3). In this chapter we set up a straw man who argued against courses on teaching methods, and then we knocked him down. The straw man is real, and we have met him many times. This book is written in a pragmatic, how-to-do-it style. The philosophical and spiritual aspects of teaching are given little attention. We recommend Palmer’s (2007) book for readers interested in these aspects.

HOMEWORK

1. Develop a critical comment about the need for a teaching course and your response.
2. Good teachers must remain intellectually active. Brainstorm at least a dozen ways a professor can do this during a 35 to 40 year career.
3. Discuss the values that influence your teaching.
4. Determine the positions in Table 1-5 of engineering professors you know. What could these professors have done to improve their teaching? (Do not identify the professor.)

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CHAPTER 2

EFFICIENCY

Professors are more effective if they learn to be efficient. Ideally, this learning would be done in school (it is helpful to be an efficient student). Most new professors work long hours and still feel they don't have time to do everything they want or need to do. By being more efficient they could do more research and do a better job of teaching in less time. Being efficient requires both an attitude and a bag of tricks. This chapter draws upon Lakein (1973, 1997), Griessman (1994), Morgenstern (2004), and Covey (1989, 2004, 2013) for many of the basic ideas. Reis (1997),Boice (2000), and Deneef and Goodwin (2007) have written guides for increasing the performance of new professors while Wankat (2002) and Robinson (2013) consider all professors.

2.1. SUMMARY AND OBJECTIVES

After reading this chapter, you should be able to:

- Set goals and develop activities to meet those goals.
- Prioritize the activities and use to-do lists.
- Improve your work habits with respect to people interactions and other activities.
- Analyze your travel patterns and improve your time use during travel.
- Explain how time spent preparing to teach affects course effectiveness, and use methods to improve your teaching efficiency.
- Improve your research efficiency and apply approximate cost-benefit analyses.
- Use methods to control stress.
- Discuss situations when a strict application of efficiency principles may not be the most efficient in a global sense.

2.2. GOALS AND ACTIVITIES

Clarifying your motivation for being more efficient will help provide the energy and drive to become more efficient (Covey, 2004; Morgenstern, 2004). Often, you know what you should do, but summoning the energy to do it is difficult. For example, you know that exercising at least three days a week is good for your health, but you often skip because . . . well, you can always find an excuse. A vision or mission for your life will help provide the energy to do what should be done (Covey, 2004, 2013; Morgenstern, 2004; Wankat, 2002). For example, some engineers want to find a cure for cancer. Yes, they know that cancer consists of multiple diseases that will require multiple cures, but their mission is crystallized in the shorthand version—find a cure for cancer. Most people who have life missions developed them slowly through working on what they believe is important and then reflecting on the results. This development probably cannot be rushed although people can prepare so that when their life mission becomes clear they are ready to focus on it.

Even in the absence of a life mission, most people know many of the things they want. To achieve what they want, they can set goals, both short- and long-term, for both work and leisure. To illustrate, a young professor's lifetime goals may include the following:

- Be promoted to associate professor and then to professor
- Become a recognized technical expert
- Be recognized as an outstanding teacher
- Develop a happy personal relationship
- Provide for children's education
- Spend a sabbatical in Europe
- Remain in good health

This is a reasonable but certainly not all-inclusive list. Your goals may be different, of course, because only you can develop your list.

A lifetime is, one would hope, a long time. Action plans are easier to develop for shorter-term goals, so a two- or three-year list of goals such as the following may be useful.

- Remain in good health
- Publish five papers in refereed journals
- Be promoted to associate professor
- Take a Caribbean cruise

Even shorter term lists such as semester lists are useful. Achieving just one or two major goals in a semester requires an unusual level of persistent effort. For this chapter to be useful you need to write down your own goals and then work to determine smaller goals that will help you achieve your major goals.

Lists of goals have the advantage of keeping you focused on the big picture, but they often include items that are difficult, which just encourages procrastination. Consider the goal "remain in good health," listed above. We can list the following smaller goals that will help one attain the goal of good health (Agus, 2014):

- Stop smoking
- Lose weight
- Be more physically active

This list is still pretty daunting and is probably too much to tackle at one time. In addition, the goals don't tell what you need to *do*. For this you need *activities*. For example, the following list will probably help someone get started on the goal of stopping smoking:

- Make an appointment to see a physician for a prescription for nicotine withdrawal
- Clean out all the ash trays and discard them

- Throw away all the cigarettes in the house
- Purchase the prescription and start taking it

Some people find it helpful to publically announce their goal so that others can be supportive while others prefer to work on the goals quietly. Do whatever works.

Activity lists should be developed for each goal. A certain amount of ingenuity may be required to develop a list of appropriate activities. For example, writing a proposal may eventually help you achieve the goal of being recognized as a technical expert. If the desired goal requires a decision by others, such as being promoted, it is helpful to determine what their requirements are for achieving this goal. Of course, requirements for promotion are often moving targets, and it may be impossible to get a firm commitment on what is required. For instance, the criteria for promotion (see Section 17.2) usually do not list the number of papers required. However, by asking several full professors you should be able to get an approximate idea of the number and type required. This gives you information to plan the right activities for reaching your goal.

Goals, whether we choose them or they are assigned to us, are extremely important, since to a large extent they control our daily work. As professors we control a significant portion of our time, but routinely fill this time with goals for teaching, research and service. Even when tasks are assigned, faculty often can negotiate what tasks they will do. For example, in many departments teaching assignments are, up to a point, negotiable. Negotiate for assignments that will help you be efficient. For example, if you will be teaching a new course, ask to be assigned it for the next three offerings so that you can reuse the material you prepare for the course. Service assignments are also negotiable. If there is a task you would like to do, make this clear by asking for it. Remember, there is a big difference between one-off and continuing tasks. A task that can be done in half a day probably just delays completing other tasks, while a continuing task often means that something else cannot be done. Department heads often need to be reminded, "If I do this task, which of my current activities do you want me to stop doing?" The same reasoning applies when other professors offer us the opportunity to work on research or other projects

2.3. PRIORITIES AND TO-DO LISTS

After goals and activities, set *priorities*. This involves juggling the order of the goals until you find an order which satisfies you now. Don't try to set priorities for all time. Goals are made to be changed. A professor desiring promotion may give that goal a higher priority than taking a long vacation. The long vacation can be seen as a reward for accomplishing the first goal. Professors usually must work on several goals at once. Choosing "maintain good health" first makes achieving the other goals easier, but maintaining good health requires a steady commitment. At the same time, courses must be well taught, research must be done, committee meetings must be attended, and so forth.

Meeting goals requires a day-by-day commitment. *To-do lists* and *calendars* help ensure that high-priority items are worked on. A to-do list delineates the activities that you want to work on within a given time period. Good choices are daily, weekly, and semester to-do lists. A semester to-do list includes only major projects such as papers, proposals, and books. This list is glanced at when weekly lists are prepared. A weekly to-do list includes the activities you want to do that week. Many of the activities may be assigned duties that are indirectly related to your lifetime goals, since doing them well will help you keep your job and perhaps be promoted.

Include some discretionary activities related to your high-priority goals. Also include non-work activities that are important to reaching your goals, such as swimming three times a week to be physically more active. The type of calendar used is unimportant so long as you use it. When we get busy, external memory (the calendar) is much more reliable than our own internal memory.

An ABC system can be used to set priorities (Lakein, 1973, 1997). List on your to-do list the important items to do in the near future as A's. Include work items that have to be done, such as writing a series of lectures or a proposal. Also include activities that will help you achieve your lifetime goals and which you chose to work on this week. Include on the A list large, long-term projects such as writing a book. A mix of things that you have to do and things that you want to do makes work more pleasurable. The A jobs should be worked on during periods of peak efficiency. Putting an item on the A list does not mean that you will finish it today or this week or even this year. Instead, it is a commitment to spend a minimum of five or fifteen minutes on the activity. The purpose of this is to break down overwhelming tasks into little pieces to prevent procrastination. The five to fifteen minutes may grow into several hours of effort once you get started.

Lakein (1973) suggests listing the A activities in order of priority, A1, A2, and so forth. B items are either less important or less urgent. If there is time, you can work on them this week. If not, the B's and perhaps some of the A's will wait for next week. C items are even less important and are held in reserve. Sometimes these items take care of themselves and there is no need to work on them. Priorities change. A paper due August 15th may be a C in June, a B in July, an A in August, and an A1 on August 14th.

Begin the week by listing the highest priority activities on daily to-do lists. If you don't get to an activity on Monday, work on it on Tuesday. On Friday, check to see which A's haven't been worked on. Either work on them then, or move them to next week's list. We found that there was no reason to continue to list B or C items since we always had more A items than we could finish. You may want to omit routine meetings and class meetings from the list since they are recorded in your calendar. If you can, arrange your schedule so that you have a chance to work on items on the to-do list early in the week and a chance to clean up at the end of the week.

It is useful to realize that most of the time urgent does not equal important. Keeping up with the literature in your specialty is important but rarely urgent. Priorities help you to be sure that important but not urgent things are done. There are urgent but less important chores such as committee work, writing thank-you notes, and preparing expense reports that must be done. Do these all at one time when your energy is running low and you need a break from important activities.

In setting up priorities it is useful to think about *critical paths* for large projects. Think about what needs to be done in what sequence so that the whole project can be completed quickly. This is illustrated in Figure 2-1 for an experimental research project. It is important to do the preliminary design quickly so that equipment can be ordered. New graduate students often do not realize that it may take from one month to more than a year for equipment to arrive. If ordered early, the equipment may be available when the experimenter is ready for it.

Ideally, researchers will follow the straight path through the entire process; however, this seldom occurs. Usually, there is significantly recycling back to one of the earlier steps. After recycle some of the intermediate steps may be skipped (for example, when a close look at the system as actually constructed helps to explain unexpected experimental results). Note that we recommend that the parts of the paper should be written throughout the research project.

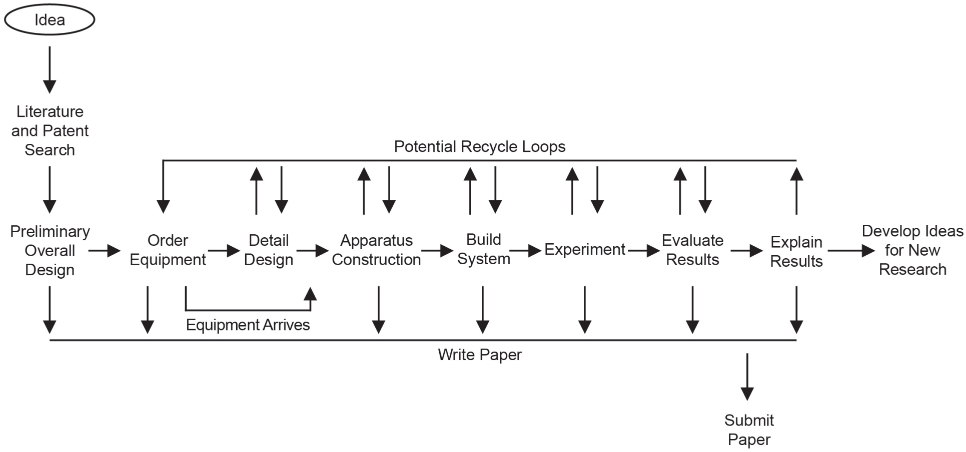

Figure 2-1. Critical Path and Potential Recycle Loops for Experimental Research Project

A major problem with planning, to do lists and schedules is that people routinely overestimate how efficient they will be and underestimate the time required to complete tasks (Dunning et al., 2004). As an example, we did not graduate with our PhDs when we thought we would and we have never had an MS thesis student or a PhD student graduate on time following their schedule. This *planning fallacy* occurs even for worst-case scenarios.

A second problem with priorities and to-do lists is becoming too work-oriented and forgetting to "stop and smell the roses." Loosening up on the rigidity of the list will probably help. Consider most items on the list as a guide and don't worry if you don't work on a particular task. Try to be productive without being rigid about following a schedule. Saturated with one project? Switch to something else. This is often a good time to initiate people contact either face-to-face or electronically. Alternatively do non-urgent but important chores.

2.4. WORK HABITS

Goals set? Activity lists developed? It's time to consider our work habits. Work habits have a major effect on how efficiently we satisfy our goals and thus are the subject of many books on time management and efficiency (e.g., Covey, 1989; Griessman, 1994; Morgenstern, 2004; Lakein, 1973, 1997; Mackenzie and Nickerson, 2009).

2.4.1. Interactions with Coworkers

Visiting. Much of a professor's time is spent interacting with various people, so your work habits involving people are important. Determine when and where you work most efficiently by yourself and with others. Some prefer blocks of time in the morning to work alone, while others prefer the afternoon. For some an hour at a time is sufficient, while others need much longer periods. In working with others, do you prefer a formal schedule or an informal drop-in policy? Only you can determine these individual preferences. A useful way of looking at these individual preferences is with the Myers-Briggs Type Indicator (MBTI), discussed in Chapter 13.

Once you have discovered the most efficient way to work, arrange your schedule and control interruptions and visitors. Listed office hours are very useful. If a student comes in at another time when you are busy, say, "I only have a couple of minutes now, but I'd be happy to spend more time with you during my office hours." This approach is most acceptable to the student if you have office hours four or five days a week and you have the reputation of being in your office for your office hours. Of course, students prefer an open door policy. A second method to control interruptions is to say *no,* but this is only acceptable to students if you share a good reason, such as preparing for a class in one hour, and if you can offer an alternate time.

Controlling the length of visits is also important. Perhaps surprisingly, the worst offenders are often colleagues. When the visit has lasted long enough, stand up and say, "It's been nice talking to you, but I have to get back to work." With more senior professors you can joke that the work of assistant professors is never done. Escort your visitor to the door and invite them to visit again. Controlling the length of visits can be done politely but firmly.

Another method for controlling interruptions is to hide. A second office or an office at home or a table at a local coffeehouse can be a good place for work requiring solitude. Most students do not become upset if they can't find a professor, although they become very upset if they find the professor and he or she does not have time to talk.

Secretaries. Some universities do not provide secretarial assistance to professors because of budgetary constraints. This short-sighted view squanders the much more valuable professorial resource. Unless you have had industrial experience, you probably have never worked extensively with a secretary. The situation is complicated since you are undoubtedly not the only boss and are probably one of the less important bosses from the viewpoint of your secretary. If you are lucky enough to have the services of a secretary, how can you best use her or his capabilities to help both of you do your jobs better?

Peters and Waterman (2004) note that outstanding companies obtain productivity through people. A productive professor treats secretaries, teaching assistants (TA) and undergraduate assistants (UGA) with respect. Realize that they have other responsibilities besides your jobs. Plan ahead and help them plan ahead. Develop a "win/win" atmosphere where both you and your office or research staff can work efficiently (Covey, 1989). If you have a number of assistants working with you (e.g., as TA and UGA for a large course) it is important to communicate clearly so that everyone understands what you want. Try to make your staff partners with you even though they only work part time with you. Short weekly meetings allow you to go over what needs to be done that week and it gives everyone a chance to determine how the work will be accomplished. Since students all have other duties, encourage them to trade off tasks when necessary. But be sure that the trades are written down so that everyone has a clear to do list. If there is not a close deadline, ask if one time is better for getting a project done than another. Give a warning when there is a big project such as a proposal coming up. If something is not needed quickly, provide a due date. If you consistently give materials on time, then when there really is a big rush, your fairness will be rewarded with an all-out effort. When someone has really gone out of the way to help you with a big project, reward him or her appropriately—candy, flowers and gift certificates are always appreciated. Praise never goes out of style. Finally, your mother was right—"please" and "thank-you" are magic words.

Teaching Assistants. Both undergraduate and graduate teaching assistants can be extremely helpful, particularly in large classes. However, new teaching assistants often have no experience in grading and need to be trained. Your goal is to make the TA a partner in teaching the course. Discuss the following before the semester starts.

1. *Your expectations*. TA duties usually start before the semester starts and continue until grades are due. The TA may not realize that he or she has contracted for this time.
2. *Attendance and note taking at your lectures*. Otherwise, the TA will be very rusty in grading and helping students.
3. *Proctoring tests*. In large classes extra help is always useful.
4. *Office hours*. Help the TA set required office hours at times convenient to both the students and the TA. Adjusting office hours weekly to meet student needs will significantly increase student attendance at office hours (DeVilbiss, 2015). Expect the TA to be available during office hours but protect him or her from excessive demands from students at other times.
5. *Scoring*. Explain in detail how you want scoring done (see also Section 11.3). Remember this is probably a learning experience for the TA or UGA also. For the first few assignments grade a few problems to serve as examples. Check over the scoring and give feedback so that the TA or UGA can improve as a grader. Expect a reasonable turnaround on grading, but tell graders in advance when a heavy grading assignment will be coming. If students ask for regrades, work with the grader. Listen to the TA's rationale for assigning grades. Try to balance consistency in grading with fairness.
6. *Recording grades*. One TA can be responsible for the online gradebook.
7. *Student interaction*. If laboratory or recitation sections are involved, encourage the TA to prepare ahead of time and to learn the names of students. Laboratory TAs should know how to operate all the equipment and they should be aware of any safety hazards.
8. *Efficiency*. Arrange the TA's workload so that it can be done in the amount of time the person is being paid for.
9. *Professional expectations*. Clearly explain your and the school's expectations for professional behavior.
10. *Training program*. If one is available, encourage or insist that your TA enrolls. TA training programs that include multiple components such as practical pedagogy, practice teaching, and opportunities for discussion increase the performance of TAs (Richards et al., 2012).
11. *Reflection*. TAs will gain more from the experience if they reflect on both the positive and negative aspects of being a TA (Wiedert et al., 2012).
12. *Mentoring*. TAs who are interested in becoming professors should be mentored so that the TA position also serves as a professional internship.
13. *International TAs*. TAs from other countries will often benefit from contact with American undergraduates and the undergraduates often gain a better understanding of other cultures from international TAs. However, international TAs, particularly those who were not undergraduates in the USA, often have difficulty adjusting to American customs. Student-teacher interactions may be different than in their home country, and American students may appear rude or overly informal. You may need to explain clearly to international TAs that US standards of behavior in many pro-

fessional areas, such as behavior towards women, are different from those in many other countries. Students lacking fluency in English should not be used in positions where they will have extensive contact with students.

Other Support Personnel. There are always other personnel in the department who do important work but are often ignored. They include janitors, shop personnel, laboratory instructors, instrumentation specialists, storeroom clerks, business office personnel, information technology people, and so forth. Treat them and their work with respect. Many of the support personnel are interesting people with a long history in the department. Be friendly and listen when they talk. Since their viewpoints are different from professors', you can learn things you will never learn if you only talk to professors. If you feel comfortable with it, ask them to call you by your first name. In some departments they have significant student contact, and they may know the students better than most of the professors. If so, they can be very helpful if you have any problems with particular students.

A professor must be honorable and honest in all dealings with secretaries, TAs, and other support staff. Thus, do not ask them to do personal favors or anything illegal or unethical. Respect their privacy and what little personal space they have. Ask permission before you borrow any equipment or use any of their equipment such as personal computers. Finally, be sure that your TAs and research assistants also treat the support staff appropriately.

2.4.2. Miscellaneous Efficiency Methods

Covey (1989), Lakein (1973, 1997), Mackenzie and Nickerson (2009), Robinson (2013), and Wankat (2002) suggest a variety of methods for improving the use of time.

Avoid perfectionism. Manuscripts can be revised endlessly, and yet the reader will never think they are perfect. At some point you have to let go and put out a less-than-perfect, but not sloppy, manuscript. This same reasoning is applicable to other work such as lectures.

Reward yourself and take breaks. Most of us become very inefficient if we try to work all the time. You might recommend to your graduate students that they take at least one day a week off and do no work on that day. This will pay off in terms of long-term efficiency, and overall work production will actually increase despite working fewer hours. Most people also need vacations (even assistant professors). Over a five- or six-year period an assistant professor will probably enjoy life more and get more done if he or she takes at least one week of vacation every year.

Use the same work several times. The most obvious application of this is teaching the same course several times. Then the work spent in setting up the course is reused when you teach it the second and third times. Teach courses in your research area. Time spent on research will help you present a more up-to-date course, and time spent on the course will help you better understand your research area. Another example is the preparation of a literature review. This work can be published, serve as the literature review of a proposal, be presented as a paper, or serve as the basis for several lectures.

Bogged down? Change your work environment or your task. Carrying work to the library, college union, or local hangout can provide just the change you need. Switching tasks can also provide a needed break. If proofreading has you down, read a technical journal for half an hour.

Use odd moments to do useful work. Can you do useful work while you commute on public transportation to work? (Note that relaxation may be the most useful thing to do.) Plan work for trips (see Section 2.4). Take a book or papers to grade to the doctor's office. Figure out what works for you for those ten- or fifteen-minute periods that are not long enough for a "serious" project.

Do not multi-task. Although many people, particularly students, think they are good at multi-tasking, they have not compared how much they accomplish compared to focusing their attention on a single task. Scientific studies show that no one is good at multi-tasking (Chew, 2011). This is particularly true if the task requires concentrated effort such as studying.

Handle mail and e-mail more efficiently. The general rule is to minimize the number of times you handle it. There is no law that says that you must open junk mail or junk e-mail. If you *do* open a piece of mail or an e-mail, try to respond immediately or at least be sure that you do something to move it forward each time you pick it up. You can help your correspondents by including your telephone number and e-mail address in your messages.

The advent of e-mail brought on a host of problems that seldom occurred with regular (snail) mail. Regular mail normally was safe and did not carry viruses. Even with virus protection opening unknown files is dangerous. Ironically, e-mail and Twitter go out too quickly. With regular mail there would be a wait while a secretary prepared a corrected, neat copy of the letter. During this wait people could calm down and decide that sending the letter was not wise. E-mail and tweets can be sent immediately and cannot be recalled. So, never send an e-mail or tweet when you are mad. Proofread all e-mails. Many readers will dismiss your e-mail if it is poorly written. Recipients are more likely to read your e-mail if the subject line is specific about the topic. E-mail and tweets also have the annoying habit of showing up at inconvenient times. There is no law that says you have to open it or respond immediately. If you do not have time for a detailed response, send a short e-mail stating that their e-mail has arrived and will be answered in a day or two when you have time to provide the measured response it deserves.

Carry a small notebook, pocket calendar, smart phone, or other scheduling device at all times. Then you can record appointments and, if necessary, transfer them to another calendar later. This helps you to avoid missing meetings. The notebook or device can also be used to jot down ideas, record references, list names of people you meet, and so forth.

2.5. TRAVEL

Travel can be exhilarating and broadening, but also exhausting. The interest and energy generated is very high when you seldom travel (say, once or twice a semester). As you travel more often, the interest in each trip decreases. The first trip is very exciting; the fifth trip in the same year is a lot less so. Every trip involves a certain amount of hassle in developing plans, buying tickets, arranging for colleagues to teach your classes while you are gone, and so forth. In addition, when you return you have to catch up on the work you missed while you were gone. These hassles and the work you have to make up lead to a tiredness factor. Cumulatively, tiredness increases as you make more and more trips. The combination of interest and energy generated by the trip and energy drained by the trip is the efficiency curve shown in Figure 2-2. This curve goes through a maximum at a certain number of trips per semester. An additional factor is the effect of your travels on your spouse or significant other. (Even pets don't like to be left alone.) However, a partner who travels with you may be more positive about traveling, and a partner can help reduce the tensions of traveling.

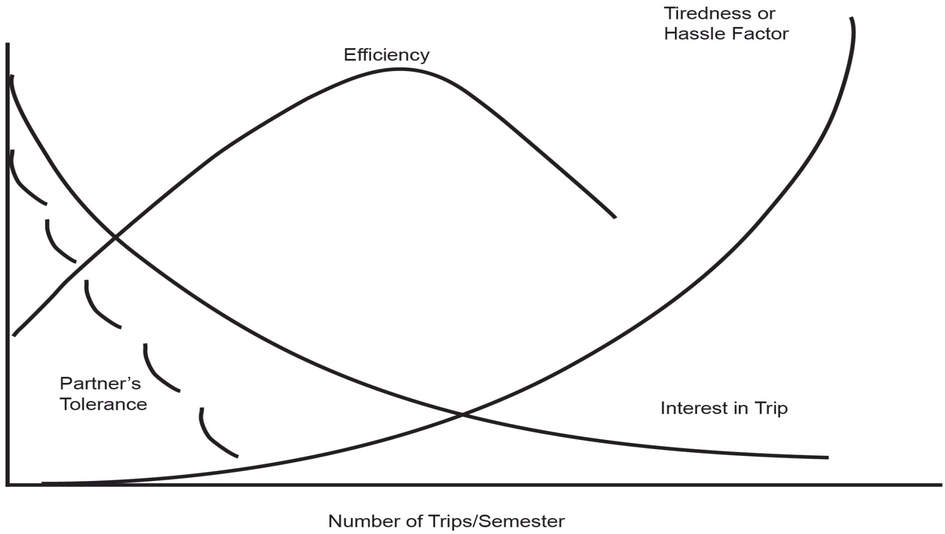

Figure 2-2. Effects of Travel

There are no numbers on Figure 2-2 since the values depend upon individual circumstances. If you're not feeling well, one trip may be too many. Extroverts tend to like traveling more than introverts do, probably because the hassles are not as draining for extroverts. The point of Figure 2-2 is that there is an optimum amount of travel for you.

Not traveling may lead to stagnation, parochialism, and a lack of name recognition. There are several dangers in traveling too much. Certain responsibilities such as office hours, committee meetings, and academic advising really cannot be made up. Being gone too much risks the danger that classroom effectiveness may plummet (see Section 2.6). It will probably take one day to catch up for each day you are gone. If you are gone a week, it will take a week to catch up, and that will be two weeks you do only routine and urgent tasks and don't get a chance to work on important goals. Ask, "Does this travel help me reach my long-term goals?" Sometimes travel helps you reach some goals, such as increasing your name recognition but hinders reaching other goals such as writing a book. If you decide that you are traveling too much, then say no to less important trips and develop a standard e-mail for declining invitations.

When you do travel, a good secretary who understands travel is very important. For a very complicated trip, such as three weeks covering five universities in Australia and three in New Zealand, it will be worth the expense to work with a good travel agent. Shop around until you find an agent who will work with you, and then stay with that person. Currently, planning ahead, getting your tickets early, and being flexible as to the dates you travel can save money. An extra day to be a tourist or just relax can be the difference between an enjoyable trip and an exhausting one. Registration fees at conferences are lower if you register early.

Use the time spent on airplanes to get some work done. A long flight may represent the longest period of uninterrupted time that you'll have in months. Bring a combination of writing projects and reading, such as a book or some articles to review. If possible, also bring some light technical reading. When the flight is at night after a busy day, you may decide that a review of the day and sleep are more important than doing more work.

2.6. TEACHING EFFICIENCY

Courses can be organized so that they are efficient for everyone involved. First, ask colleagues who have taught the course previously if they will share course materials with you. If asked, many senior colleagues are happy to share materials and discuss teaching. Either adopt the course goals and objectives used previously or develop new ones. If the course has never been taught at your institution, search the web for similar courses to provide ideas. Then decide upon the course organization and teaching method. The lecture method is most commonly used since it is widely believed to be the most efficient use of a professor's time. This may be true the first time a course is taught, but other methods can be equally efficient the second and subsequent times the course is taught. Active learning methods are usually more efficient for students since they learn and remember more material. Develop a tentative course schedule including exam dates before the semester starts, and hand it out to the students and the TA at the first class session. This allows them to plan for tests and projects. Calling it a "tentative" course schedule gives you flexibility you may need if it becomes necessary to adjust the schedule.

Homework and tests can be developed efficiently. Solving problems before they are used practically eliminates using problems that either cannot be solved or are too easy. As a rule of thumb, you should be able to do the test in approximately half the time graduate students will require, one-third the time junior and seniors will need and one-quarter of the time sophomores will take. Occasionally using a homework problem or lecture example on a test emphasizes the importance of doing homework and paying attention during lecture (Christenson, 1991). Ask TAs to solve some of the homework problems, but check their solutions. On tests we have the TAs solve the problems they will grade and compare answers with our answers. Solving problems before grading improves the grading. If you award partial credit, give the TA your solution plus a scheme for awarding partial credit. Check your grading scheme by grading half a dozen tests. Be particularly mindful that there may be alternate correct solution paths. Requiring written requests for regrades drastically reduces the number of arguments you have to confront. For unusual assignments such as an essay, provide the students with a couple of exemplars in advance so that they have a better idea of what you want. Use a rubric (see the Chapter 4 Appendix) when grading speeches or essays.

Preparing for a lecture immediately before the period it will be given ensures that you are fresh. When presenting a lecture given previously, learn to revise and prepare the lecture in one-half to three-quarters of an hour. For totally new lectures or major revisions develop the ability to prepare a fifty-minute lecture in two hours or less. These time limits prevent Parkinson's law (work expands to fill the time available) from controlling your time. Of course, if you don't understand the material, much more time may be required. Time can be saved in lecture preparation by using examples from other textbooks. This is preferable to repeating an example from the assigned textbook. Most new faculty members drastically over-prepare and spend much more time than we have suggested here (Boice, 2000). In some engineering disciplines screencasts are readily available and can be used to provide students examples on their own time (see Chapter 8).

You may be tempted to use someone else's lecture slides or the slide set that is bundled with the textbook. Use of a few graphs, figures, or images can be helpful, but adopting more is a false economy. It is difficult for most professors to present material they have not prepared spontaneously and convincingly. Lectures presented from another professor's materials are likely to be very flat and uninspiring.

How much time needs to be spent on a course before it deteriorates? The answer depends upon your skill and experience as a teacher and upon your knowledge of the content. For new professors and for professors teaching a subject for the first time, more time and effort are required to do a good job (see Figure 2-3A). Our observations indicate this is generally an S-shaped curve. Effectiveness increases rather slowly at first and then speeds up as more time is put into the course. As more and more time is spent on the course, effectiveness approaches an asymptotic limit and may actually decrease slightly. As the professor gains experience in teaching and becomes more familiar with the material, the curve sharpens and moves upward and to the left to higher effectiveness with less effort.

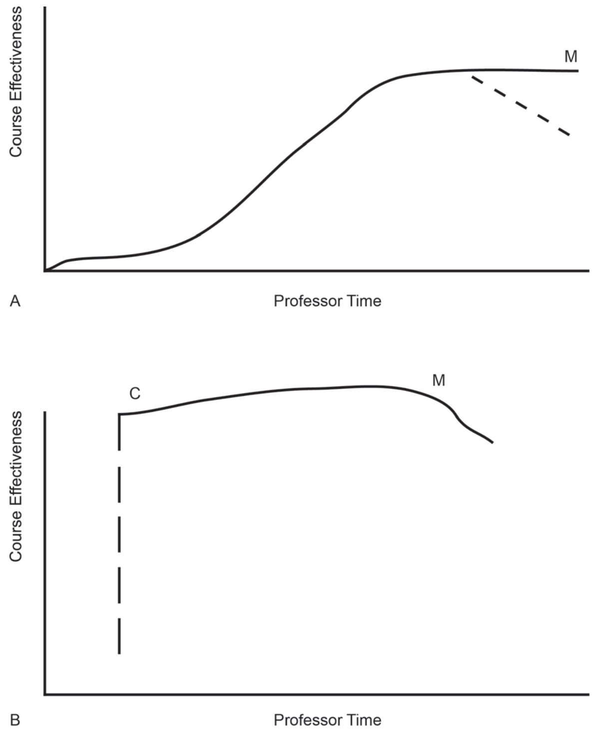

Figure 2-3. Effects of Professor's Time and Effort on Course Effectiveness: A. New Professors or New Courses, B. Experienced Professor with Established Material

The hypothetical curve for an experienced professor is shown in Figure 2-3B. There is a very broad range of professorial effort where course effectiveness is quite satisfactory. However, at critical point C there is a discontinuous drop in course effectiveness and the course drops below acceptable levels. This drop occurs because teaching, unlike research, is always a "what have you done for me lately" activity. All the rapport and good feeling developed one semester has to be rebuilt the next semester. A professor with a good reputation will have an easier time doing this than one with a bad reputation. However, if the "good" professor does not put in enough time or is gone too often, the course effectiveness will crash. Experienced professors can hover in the flat plateau above point C and adjust their efforts if they feel the class is slipping. This is somewhat dangerous, particularly if the class is slipping because of too much travel. Note in Figure 2-3B that experienced professors are more likely to have a maximum, point *M*, beyond which extra effort actually decreases class effectiveness.

Students also appear to follow the curves in Figure 2-3. Figure 2-3A refers to students who are not experienced learners in a particular area, and Figure 2-3B to those who are very experienced in a given area.

2.7. RESEARCH EFFICIENCY

At research universities, even professors who are dedicated to teaching need to conduct research if they expect to be promoted and tenured. Barker (2010), Reis (1997), and Wankat (2002) focus considerable attention on research. Reichert et al. (2002) consider the start-up process for new professors at research universities.

An excellent, efficient research program will follow many of the same basic principles as a well-run company. The following principles are adapted from Peters and Waterman (2004) and Wankat (2002).

1. Be action-oriented. This is Covey's (1989) first habit of effective people.
2. Pay attention to the customer. For research the customers are the company, foundation, or government agency supporting the research and the readers of articles from the research.
3. Supervision of graduate students should aim for a happy medium between too little and too much as discussed in Section 10.5. Within broad guidelines, give graduate students control and responsibility. Do not spell out the nitty-gritty details. Regularly scheduled meetings can prevent excessive procrastination.
4. Show respect for each research student. One way to do this is to listen more and talk less.
5. Be hands on and driven by values. Visit the graduate student's laboratory or office. Continually remind them of the basic value of the research group (e.g., "innovation" or "careful experimentation").
6. Develop a balance between doing research in your area of expertise and working on creative ideas. You don't want to develop the reputation of continually repeating the same research, but there needs to be some coherence in the research projects. Before starting a new project ask, "Do I have the skills, time, and energy to do a good job?"
7. Develop an energized atmosphere with the expectation of regular contributions from every group member.
8. Finish the research and publish.
9. Unfortunately, professors are in a business where rejection and professional snubs are not uncommon. This is a secret we keep from graduate students interested in academic careers. Find a way to constructively deal with rejection such as the REBT method in the appendix to this chapter.
10. Do research that excites you.
11. No proposal, no money.

It is easiest to get results and write publications when you work on new ideas instead of following the well-beaten research track. Thus, time spent on generating new research ideas usually pays off. Many articles and books have been written on creativity (see Section 5.7). Application of these creativity methods can lead to more impactful research.

Many universities want to see proof that assistant professors can obtain research funds both on their own and as part of a collaborative team. Proposals written by a team of researchers with complementary skills usually take more time to write, but are often more likely to be successful than individual investigator proposals. If approached about joining a team to write a proposal, you need to consider several different facets. Is your part of the proposed research within your area of expertise and does it fit into your long-term research plan? Do you have time? What will you not do if you work on the proposal and if the proposal is funded? If working on the proposal will make you give up something very valuable, saying no may be the best option. Do you want to work with your colleagues on the proposal team? Follow your instincts when determining the answer. Saying no to senior colleagues can be tricky. Develop a reason for saying no that has no negative connotations about the research team or the quality of the research. For example, a new baby in the family or the need to finish writing a textbook are almost always acceptable.

A useful method to determine semi-quantitatively if a particular project is worth doing is a *cost-benefit analysis.* Cost-benefit analyses can be done for projects other than research, but they are easy to illustrate for comparison of proposals since monetary value is involved. The benefit-to-cost ratio in dollars per hour for writing a proposal can be estimated as

$$\frac{\text{Benefit, \$}}{\text{Cost, hours}} = \frac{(\text{Money received}) \times (\text{Probability of funding})}{(\text{Hours writing proposal})} \tag{1}$$

where the number of hours required writing the proposal is approximately

$$\text{Hours of writing} = k \times (\text{number of pages}) \tag{2}$$

The value of the proportionality factor k depends on your speed and that of your collaborators. The probability of funding is harder to estimate, particularly initially when you have no experience. Some idea of this value can be determined by talking to experienced professors or by talking to the agency.

Consider two sources of funds: one offers a small amount of money but has a high probability of success, and another offers significantly more money but has a lower probability of success. The following approximate comparison can be done.

Source A. \$25,000, requires a ten-page proposal, and has a 50% chance of funding:

$$\text{Benefit/cost(\$/hour)} = \frac{\$25{,}000}{10k} \times 0.5 = \frac{1250}{k}$$

Source B. \$500,000 (for 3 years), requires a twenty-page proposal, and has a 10% chance of funding:

$$\text{Benefit/cost(\$/hour)} = \frac{\$500{,}000}{20k} \times 0.10 = \frac{2500}{k}$$

On the basis of the cost-benefit ratio alone, source B looks more advantageous. However, there may be other reasons for trying source A first:

1. Need to quickly show success in obtaining funding.
2. Grant is small but prestigious.
3. Grant is for a proof of concept and could easily lead to much more money later.

It may be possible to send very similar proposals to both organizations, but this is ethical only if you inform the agencies of your intention.

A final comment on writing proposals and papers: *always check your references.*

2.8. HANDLING STRESS

Professors and students often feel significant stress. Modest stress may increase efficiency and not be harmful to health. But after some point stress can decrease efficiency and become harmful. Some people can thrive in an environment that is very stressful for others. Three approaches to handling stress are: change of environment, change of perception, and relaxation methods (Wankat, 2002).

Changing the environment is a very effective way to reduce stress. Sometimes all that is needed is the realization that there are alternatives. For example, professors who find lecturing to be very stressful can use other teaching methods once they realize they exist. A professor who finds the noise from a student lounge to be annoying can ask to be assigned another office. Professors may find that parts of their lifestyles are increasing their stress levels, and this stress can be reduced by changing lifestyles. Even excessive caffeine intake may increase stress. People with certain medical conditions may find that some weather patterns cause them physical stress. Alleviation of this problem may require moving to another university in another section of the country. Some people find all aspects of a professor's life stressful. Their only solution may be to find a job in industry or in a government laboratory. Often a stressful part of the environment can be changed only by a major move, and other aspects of the position make such a move undesirable. In cases such as this it is important to learn to manage the stress.

An effective method for managing stress is to change your perception—how you feel and react to incidents (Ellis and Harper, 1997). Everyone has a surprisingly large degree of control over how they feel and react to situations. Some professors feel that they have to be perfect and thus become very upset if a class does not go well or a research paper is harshly criticized. As a result they may be unable to function. Individuals with a need to be perfect will be happier and more efficient if they learn to accept some imperfection (see Chapter 2 Appendix). A similar problem arises with those who feel responsible for the actions of others. For example, most professors do not enjoy flunking students, but some find doing so to be extremely stressful. They feel that the F is their responsibility instead of the student's. It is much less stressful and fairer to assign this responsibility to the student where it belongs. Alleviating the problem of assigning yourself too much responsibility is possible by the same methods which work for over perfection. A related problem is the *catastrophe syndrome*—believing that a catastrophe will occur if something happens or does not happen. The something can be rejection of a paper, low teaching ratings, denial of tenure, or whatever the professor wants to name. Admittedly, none of these are pleasant, but they are catastrophes only if perceived that way.

Many psychological methods can, with the help of a counselor or psychologist, be used to overcome perception problems that increase stress. Rational emotive behavioral therapy (REBT) can be learned and applied to oneself (Ellis and Harper, 1997; Ellis, 2006). Essentially, REBT postulates that we think irrational, unhealthy thoughts and it is these thoughts that make us feel bad. The solution proposed by REBT is to rationally attack the irrational thoughts and change our thinking patterns. REBT is particularly appropriate for engineers who are trained to think rationally. The REBT approach is briefly outlined in the Chapter 2 Appendix.

The perception of stress can also be reduced by desensitization procedures (Humphrey, 1988) that involve repeated exposure to the stress-causing stimulus, but in a relatively supporting and nonthreatening environment. In a clinical setting the exposure is usually obtained by imagining the stress-causing event. In classical applications of desensitization the stimulus is first present at a very low level, and then gradually the level is increased. This may sound complicated, but it is not uncommon for professors or department heads to apply a similar procedure. For example, a new professor may first be assigned to teach a graduate class with ten students, then an elective class with thirty students, and finally a required sophomore course with 150 students. This individual will become somewhat desensitized to the stress of presenting a lecture to a large audience. A professor who gives many quizzes in class is in effect desensitizing students who have problems with test anxiety. This method is most effective if the first quizzes are worth a smaller proportion of the course grade than later quizzes, or if a practice test is given.

Relaxation techniques are useful for reducing excessive stress while it is occurring (Humphrey, 1988; Whitman et al., 1986). Methods useful in helping one to relax include physical activities such as jogging, tennis, swimming, or walking. Regular weekend activities, particularly those that get you outside and involve physical activity, help to keep stress from building up.

Activities that result in *flow* are particularly good for taking your mind off of daily stressors (Csikszentmihalyi, 1990). Flow, which occurs when one is totally immersed in the activity, is more likely to occur when one has control, can set feasible goals, plays according to rules, obtains feedback on achieving goals, focuses attention, has a balance between challenge and skills, and can increase challenge/skills to avoid boredom. Examples of flow activities are cooking, fishing, wood working, playing a musical instrument, golf, and other sports.

It is important to *get away* and not carry work with you. Professors used to have the advantage that they did not regularly carry paging devices with them. Now that professors carry their cell phones or smart phones everywhere, stress levels and burnout appear to have increased. The ability of computers to convert work from being done mainly in the office to a 24/7 activity is a good example of the increase in stress caused by not controlling technology.

There are other useful relaxation methods. Although less popular now, transcendental meditation (TM) or repeating a mantra works for many people (Humphrey, 1988). A westernized version of TM is given by Benson and Klipper (2000). Various breathing exercises can be as simple as taking a deep breath, holding it for ten seconds, and then slowly letting it out. This simple exercise is useful to hold in reserve in case a student becomes extremely anxious during an examination. Various stretching exercises and methods to relax one set of muscles at a time are also useful and easy to learn. Humphrey (1988) presents a variety of simple exercises that can be used to reduce stress.

Excessive stress can be very detrimental to students. It is helpful to be able to recognize this and help the student cope with the stress. The procedures for doing this are similar to those for coping with your own stress and are discussed in detail by Whitman et al. (1986).

2.9. LIMITATIONS

Efforts at efficiency can be overdone, and many things cannot be done extremely efficiently. Most activities that require personal contact with other people have some built-in inefficiency. Examples include:

- Starting a class period
- Tutoring
- Advising students
- Mentoring graduate students
- Building consensus (e.g., within a department for a curriculum revision)
- Marriage
- Raising children

If you try to do these activities in a very efficient manner, then others may feel rushed and devalued. The net result is a rapid transaction that may minimize your time but is not efficient since what needs to get done doesn't get done. A classic horror story, which may be true, involves a professor who set a three-minute egg timer whenever a student came in to ask a question. After a short period most students stopped coming in, and the professor saved himself time, but he did not help students learn. Limit interruptions by scheduling personal contacts at specified times of the day. This will help overall efficiency even though the individual interactions are inefficient.

Innovation and creativity in research and teaching tend to be messy and not particularly efficient processes. It is hard to sit down and say, "In the next ten minutes I will have a brilliant idea." The paradox here is that being innovative and creative can drastically increase your overall efficiency even though the processes themselves are inefficient. Once a professor has a great idea for research, actually conducting the research may be relatively quick and easy. In addition, the research may have considerable impact. To a lesser extent, the same is true of creative ideas in teaching. Students enjoy a bit of change and creativity in their classes.

The planning of an entire career does not appear to be an efficient process, despite many books and courses on career planning. Many biographies and autobiographies tell of famous people who go through a period of wandering about before they seize upon their life's work. There are often false starts and failures until they settle down into their great work.

It is useful to separate tactics from strategy. Efficiency is almost always a good idea in day-to-day tactical concerns such as preparing for a class. If you want to break new ground in research or develop a new teaching method, it is probably not possible to have an extremely efficient long-range or strategic plan.

Relaxation is necessary to be efficient over long periods; however, relaxation itself almost appears to be the opposite of efficiency. As noted in Section 2.8, we can learn to relax better or more efficiently. During the period of relaxation, it appears that nothing useful is occurring, yet useful things must be occurring. The paradox that we must learn to live with is that only by allowing for inefficiencies can we truly be efficient.

2.10. CHAPTER COMMENTS

It is easy to get the sense that we believe your life should be absolutely centered on your faculty position. We don't believe this. Sigmund Freud was closer to the truth, "Love and work . . . work and love, that's all there is." Balancing work and your personal life can be challenging. At times one needs more attention—sometimes a lot more attention—and at times the other needs more attention.

One of the common problems in designing a course or a textbook is that there is no order that really works. There is always some part of the subject that should be discussed before covering the current topic, but not everything can be last. In addition, for motivational purposes it is useful to present a practical part of the course early so that students know why they are studying the theory. Not all aspects of this chapter will be completely clear until other chapters have been covered, and some won't be clear until after you have had experience as a professor. We put this chapter early to help you think about being efficient when designing courses. In addition, putting important material early in a course ensures that sufficient time will be devoted to it. This illustrates a second problem in course design: The most interesting and most useful material such as efficiency and creative design is often left until last so that all prerequisite material can be covered first. When this is done, the interesting material is crowded into the end of the semester when there is never enough time and everyone is tired.

Teaching efficiency in class is a challenge. The concepts are simple and often just common sense. The hard part is applying the principles. Perhaps the best approach would be to not lecture but require students to apply one or two principles to their lives. Then three or four weeks later require an informal oral report on the results. We have found that experienced professors are much more attentive and receptive to a lecture on efficiency than graduate students.

Effective collaboration and networking have become much more important for professors in the last 20 years and are discussed in Chapter 17.

HOMEWORK

1. Develop your lifetime goals as of now.
2. Develop your goals for the next three or five years, whichever time frame appears more appropriate.
3. Develop activities that will help you attain your lifetime goals.
4. Develop activities to help you attain your goals for Problem 2.
5. Assume one of your goals is to become a good teacher
   a. Define the term "good teacher."
   b. Develop activities to reach this goal.
   c. How will you know when you have reached this goal?
6. Develop a semester to-do list. Be sure to include some of your activities to reach your goals on this list.
7. Explain why a professor's effectiveness in teaching a class or a student's effectiveness in taking a class will crash if some minimum amount of time is not put into the course.
8. Learn one relaxation method and practice it every week for two months. After two months, you will probably have developed a new habit.

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APPENDIX. THE RATIONAL-EMOTIVE BEHAVIORAL THERAPY (REBT) APPROACH

The REBT approach postulates an ABC method of viewing human reactions. The *activating experience* A is the outside stimulus that the person reacts to (e.g., bad reviews of a research paper or the acceptance of a paper). Step B consists of the *internal beliefs* which lead the person to interpret what has happened. These beliefs can be rational or irrational. For example, a rational belief is that a rejection is unfortunate since more work will be required, but that the rejection is not a catastrophe. An irrational belief is that rejection is a catastrophe which *must* not happen. Eventually, the person experiences an *emotional consequence* C which he or she thinks is caused directly by activating experience A. An emotional consequence C is anger and depression. Thinking that A caused C is irrational. This must be irrational since another person will react to the same A in a very different way and experience a completely different C. The emotional consequence C is caused by the beliefs B which the person has. If these beliefs are rational, then C will be reasonable (e.g., if the belief is that bad reviews are unfortunate since they will require additional work, then C will be a mild displeasure). If the beliefs are irrational, then C can be an extreme reaction.

Most people have irrational beliefs about something. Examples of irrational beliefs are:

- It is horrible to be rejected.
- I have no control over my feelings.
- I must be liked by everyone.
- All my lectures must be perfect.
- It is catastrophic if something I do is not perfect or is criticized.

The amount of disruption these beliefs cause depends upon the belief and how strong it is.

The REBT method involves rigorously analyzing your thoughts to determine the irrational beliefs and to replace them with rational beliefs. Suppose you have just received a letter from a funding agency rejecting a proposal which you thought was very good. Your first reaction is to become angry and you know that you will be depressed and angry for several days. With the REBT approach you first stop and listen to what you are saying to yourself.

Ask, "Why am I angry?" Then listen to your own response, "Because I was turned down." Now the REBT approach pushes deeper. Ask yourself, "But why does being turned down make you angry?" Here the response might be, "Because I'm not supposed to be turned down." A further push could be, "Why aren't you supposed to be turned down?" "Because I should be perfect." "And what else?" "Well, everyone should always approve of my work."

The beliefs that one is supposed to be perfect and have everyone approve of one's work are clearly irrational. REBT postulates that the appropriate place to intervene is in the irrational belief system. Continuing our example, you could respond to yourself, "Perfect! No one is perfect. That is not rational. It's also not rational to expect everyone to like your work." Next you need to substitute a rational belief for the irrational one. For example, "A rational approach is that it is nice and certainly preferable if your work is good and is approved by everyone. However, it is not a catastrophe if someone does not like your work. It is unfortunate that the proposal was not funded since you will have additional work to do to resubmit it, but it is not worth becoming angry and depressed over for days."

This approach may sound simplistic or too good to be true. The method works but requires considerable work and practice. The irrational beliefs have been there for a long time and are usually difficult to eradicate. However, if these beliefs are attacked logically every time they appear, they become weaker. In addition, as one practices REBT on oneself, one becomes much more adept at spotting irrational beliefs and at fighting them. Readers interested in this method should read one of the books by Ellis (Ellis and Harper, 1997; Ellis, 2006).

The irrational beliefs attacked by REBT have been causing difficulties for centuries and were attacked by stoic philosophers in similar fashion albeit with a different vocabulary. Irvine's (2009) book is an excellent guide to applying stoic principles to everyday life. Perhaps because Irvine is a professor, his approach is relatively easy to apply to problems professors' experience.

CHAPTER 3

DESIGNING YOUR FIRST CLASS

You've started your first position as an assistant professor and have been assigned your first class with real students.

- What do you do?
- What teaching method do you use?
- What level do you aim for?
- How do you structure the class?
- How do you pick a textbook or other readings?
- What do you ask on tests?
- How much can you cover in a semester?
- How many tests and how much homework do you require?
- How do you grade?
- How do you behave toward the students?
- How much time will this take you?
- Why didn't someone tell you how to do this?

This chapter provides an overview of what a professor does in designing and teaching a course, and it raises a number of questions about the process. Finding some answers to these questions is the goal of the remainder of this book.

3.1. SUMMARY AND OBJECTIVES

After reading this chapter, you should be able to:

- List the salient features of different types of engineering courses.
- Enumerate the activities which need to be completed before starting a course.
- Discuss how a course is started.
- Explain the importance of the second class period and discuss appropriate activities.
- List the other important activities which occur during the semester. Explain the importance of each of these activities.

- For the preceding items discuss some of the important questions which the professor should consider when designing a course.
- Practice positive self-talk if you feel like an imposter.

3.2. TYPES OF COURSES

Engineering professors teach a variety of courses. Since course design is often different for different types of courses, it is useful to categorize courses. Required undergraduate courses that are prerequisites for other required courses tend to have the most structured content. It's likely that a curriculum committee will select the content and even the textbook. Professors who teach succeeding courses care about how well the introductory or prerequisite course is taught and the extent of the coverage. So it's a good idea to ask them what they expect. In teaching these courses you'll likely have less freedom in coverage. Balancing this, it is highly likely that past syllabi, homework, tests, lecture notes, and a recommended textbook will be available. Past instructors will be available for some assistance if asked, but you'll probably have to ask since few faculty volunteer teaching help unless asked. Often, these classes may be rather large, and student abilities will vary widely.

Required undergraduate courses which are not prerequisites for other courses are similar but have a few differences. The course content is a bit less rigid, and other professors have less of a vested interest in what is taught. These are often senior courses, which means that very weak students will not have made it this far. However, graduating seniors are notoriously difficult to motivate. Past syllabi and a textbook are probably available, but there is less pressure to follow them closely.

Required or core graduate-level courses have all graduate students in them, and class size varies from small to medium. A syllabus probably exists, but you usually are free to change it. Invariably, the amount of material to be covered is staggering, and textbooks may not be available. The research professors in the department are often very interested in the content and how well the students learn the material. These courses often give a good opportunity to get to know and impress new graduate students before they pick research topics. In some departments these courses may be considered "plums."

Undergraduate electives and dual-level undergraduate-graduate electives if offered regularly will have a sample syllabus, textbook, and tests available. Professors who have taught the course in the past are probably available for advice. Since electives are rarely prerequisites for other courses, you can usually change the syllabus and textbook. Class size is usually small to medium, and since students selected the course they tend to be interested. Overall, these courses offer a good beginning to an academic career.

Graduate-level electives and seminars are the most open in content coverage. These courses may be very specialized, and other professors often pay little attention to them as long as their graduate students don't complain too loudly. The freedom involved in selecting course content is very liberating but also daunting since well-developed syllabi, homework, test examples, and a textbook probably are not available. The classes are usually small, and the students are likely to be both intelligent and interested. The teaching of graduate electives in one's research area is an effective way to integrate teaching and research. However, professors often compete to offer these courses, and new professors may not be given the opportunity immediately.

Design courses, particularly capstone design courses for undergraduates, tend to be somewhat different from other courses. They may be taught with case studies and often are loosely structured. The workload is often high because of grading demands and the need to develop new case studies. Design courses are also sometimes associated with laboratories, which can further increase the large workload. Professors with industrial experience are often assigned to these courses (see Chapter 9).

Laboratory courses usually differ markedly from all the other types of courses (see Chapter 9). The laboratory course may be attached to another course and may or may not be administered separately. It also tends to be tightly structured since the experiments or projects are limited by the available equipment. But the equipment is often old and may not work well. Experimental write-ups are available, but always need modification. For safety reasons, the section size is usually controlled. Since teaching lab courses tends to be an unpopular assignment, the department head may staff the lab with new professors since they are most likely to accept the assignment gracefully. Although the course is required, the material covered is usually not a critical prerequisite for follow-up courses. Teaching involves a great deal of informal contact with students and extensive grading of laboratory reports; little if any lecturing is done. Some schools have added a communication component by adding a credit hour and a lecture on writing and speaking. The often extensive report writing in the course makes it a natural place for teaching such skills.

3.3. BEFORE THE COURSE STARTS

Several tasks normally need to be completed before the course starts (exceptions occur when students are heavily involved in planning the course). Some may be done for the professor if the course is well established, but with new courses all these tasks need to be at least partially completed before classes start.

3.3.1. Knowing the Audience

Talk to the undergraduate advisor in your program to find out as much as you can about the students in your course. Are most of them sophomores, juniors, or graduate students? What prerequisite courses are they supposed to have taken and are the prerequisite requirements enforced? What other courses are they taking concurrently? Are they mostly full-time or part-time students? Are they majoring in your field or are they still searching for a major? How mature are they? How many have industrial experience from co-op or an internship? In general, is it likely to be a good or poor class? The more you know about the students, the better you will be able to plan the course and select the appropriate level for the material. Student characteristics are discussed in detail in Chapters 13 to 15.

3.3.2. Choosing Course Goals and Objectives

What should the students know and be able to do at the end of the semester? This question includes both coverage of the content and the ability *to do something* with the content. Goals are relatively broad, while objectives tend to be quite specific. Your goal may be that students understand the control of systems, whereas an objective may be that they know how to use the Laplace transform in the analysis of linear control problems. The goals and objectives must satisfy what is expected for subsequent courses. The development of goals and objectives for a course is important since it controls the coverage and, to a lesser extent, the teaching method (see Chapter 4). The most important part of a class is the content covered because it makes no sense to do a wonderful job teaching unimportant material. A part of the goals and objectives for the course is the choice of the level at which to present the material. New professors are notorious for setting the level too high and being too theoretical. The choice of an appropriate level for a class is complicated (see Chapters 14 and 15). Appropriate goals and objectives depend on departmental goals and ABET accreditation; for example, since ABET accreditation requires graduates who are good communicators (see Section 4.6), writing and speaking should be incorporated into at least two the department's courses. Discuss with the department's ABET coordinator which ABET criteria should be taught and assessed in your course. Existing courses may have explicitly stated goals and objectives. For new courses syllabi posted on the internet can provide ideas of what and how much to cover.

3.3.3. Picking a Teaching Method

Once you know what you want to accomplish, you can choose a teaching method congruent with your style and with the students' learning styles and with learning principles (see Chapters 13 and 15). Lecturing and various modifications of lecturing (Chapter 6) are by far the most common teaching methods in engineering courses, and in most universities will be acceptable to the other professors in the department. Lecturing is also one of the easiest methods to use the first time you teach a course, partially because everyone is familiar with the method. But it is not the best method for many of the goals of engineering education. For example, if one goal of the course is to have students become proficient in working in engineering teams, then lectures need to be supplemented with group work (Chapter 7). No matter which teaching method is chosen, you need to check the classroom ahead of time to be sure that it is large enough and that appropriate equipment will be available.

3.3.4. Choosing a Textbook

The quality of the textbook will have a major effect on the quality of the course and on what can be conveniently covered. Unfortunately, textbooks may be selected months ahead of time because of bookstore requirements. For new professors who arrive a week before the semester starts, the book has probably been chosen by someone else. For required undergraduate courses a committee may select the book. If you do not like the textbook, plan to select a new textbook (Section 4.6) for subsequent semesters, but do *not* tell the students it is a poor book. Since many publishers have started to publish US and international editions that have different homework problems, inform students that they need access to an appropriate edition for the homework assignments.

3.3.5. Preparing a Tentative Course Outline

An outline of the entire course in advance is helpful but not essential. If time is short, outline at least the first month so that you and the students know where you are going. A complete course outline lists topics for each day. This requires that you estimate the rate topics will be covered, which is difficult, although easier if you followthe outline of an experienced professor. If you list daily topics it is useful to build in one or more open periods, or periods that can be skipped before major tests. An alternative is a partial outline that lists tests, quizzes, and student presentation days but not lecture topics. For both types of outlines you need to decide on the number and dates of tests and quizzes. Every school has breaks, student trips to conventions, and major extracurricular activities. Do you want to adjust your schedule for these events? Also, look at your calendar and adjust the class schedule if you will be out of town. Although many faculty schedule exams when they will be out of town, we suggest in Section 11.2 that professors should be present on exam days. If most of your students are scheduled in the same courses, it is useful to attempt to coordinate exam schedules with the professors teaching the other courses. In a required undergraduate course you will probably adapt the existing course outline with modest changes.

3.3.6. Deciding on a Grading Scheme

Students want to know how much quizzes, tests, a final, homework, computer problems, and projects will count. Will there be extra credit? Will you follow a 90-80-70-60 scale or will you use a curve? In our experience most students are satisfied if given an outline of the grading method. We suggest using 90-80-70-60 or similar scale as guaranteed grades, but reserve the option of using lower cut-off points. Grading is discussed in Chapter 11.

3.3.7. Arrange to Have Appropriate Material Available

Appropriate material includes the textbook and supplementary books, handouts, and solutions to homework and tests. Copies of these materials should be available to students in a library or learning resource center. Materials that you prepare for the class and expect students to download (formerly known as handouts) should be available on the class website or learning management system. Be sure the library or learning resource center has a copy of the textbook and that it is placed on reserve so that it cannot be checked out. Most major book publishers will supply a free textbook and solution manual for you. If possible arrange to have one copy at your office and a second at home. If asked, the publisher may also provide free copies for the TAs.

When making copies of any material, you need to be concerned about copyright laws and fair use (Brewer, 2008). "Broadly speaking, a 'fair use' is one where the socially beneficial results of the use outweigh the exclusive rights of the copyright holder." The law requires the following four factors be considered:

1. "The **purpose** and character of the use, including whether the use is of a commercial nature or is for nonprofit educational purposes;
2. The **nature** of the copyrighted work;
3. The **amount** and substantiality of the portion used in relation to the work as a whole; and
4. The **effect** of the use upon the potential market for or value of the copyrighted work" (Brewer, 2008).

If in doubt, it is always legal to send the students to the library to look at a legally purchased copy or to have the students access a web page that contains a legal copy of the material.

3.3.8. Developing Your Attitude or Personal Interaction Style

It helps to be enthusiastic and to believe that teaching is an important and even noble activity. How much personal warmth and caring will you show to the students? What, if any, is your responsibility for helping students grow? Is it important to you to be loved, or is respect sufficient? Do you believe all students can learn, or is removing students who cannot learn part of your job? Great teachers are marked by a deep commitment to their students. Your attitudes and style will have a major effect on your rapport with students.

3.3.9. Imposter Syndrome

Many people when faced with a new challenge feel like imposters. For example, a new engineering graduate reporting to work may believe "I have fooled them in school, but now that I am in industry they are going to find out that I don't know anything about engineering." A newly minted PhD reporting to a postdoc may feel, "I got by in my PhD research, but this is the real thing and they are going to find out I'm a fraud and don't know how to do research." The new assistant professor is older, but often no wiser. Preparing to teach the first class he or she admits "I don't know anything about teaching and I don't really understand the material. The entire class will know I'm an imposter." If any of these scenarios sound like you, then you are suffering from the imposter syndrome.

The process you endured to become an assistant professor—earning a BS and PhD in engineering, probably doing a postdoc, and surviving the interview process—is very rigorous. Imposters do not survive. Become as prepared as you can be for the first class and use *positive self-talk* and *power posing* to combat feeling inadequate because of the imposter syndrome. Positive self-talk is a method used by athletes to perform their best. It consists of reminding yourself that you have repeatedly proved that you belong in the academy and are well prepared to teach this course. Power posing, changing one's body language to exude confidence and power, changes the way people are perceived (Cuddy, 2012). Power posing such as standing with feet spread and hands on hips (known as the Wonder Woman pose) or standing with feet spread leaning forward with hands on table increases cortisol and testosterone levels in the brain and makes the person look and act more confident (Carney et al., 2010). To overcome imposter syndrome, privately stand tall and proud with arms uplifted in a V-shape for two minutes before class. Other aspects of body language are discussed in Section 10.2.3.

Once all tasks are taken care of, you are ready to start. It is usually desirable to have these chores done before class starts, but fortunately some of them can be partially delayed until after the semester starts.

3.4. THE FIRST CLASS

It is traditional to start the first class with "housekeeping chores." There are other ways to start a class and these will be discussed at the end of this section. Housekeeping chores are routine and non-demanding. They allow students to get settled in, but this is not an exciting way to start a class. Use the whiteboard to write down information and leave it on the board. Then latecomers (and there are always latecomers on the first day of class) can get the information without interrupting the class.

We also pass out a copy of the syllabus. Although we place most handouts on the web and do not pass them out in hard copy form, the syllabus is your contract with students and it is important that you know students have a copy. The syllabus should give the students all the information about the course structure that they need (Davis, 2009; Matejka and Kurke, 1994; Wankat and Oreovicz, 1999). The following items probably should be included:

1. *Course name and number*. If you are teaching first year students you will be surprised by the number of students who come to the wrong classroom. Also list the hours and the class location, particularly if two locations are used.
2. *Professor's name, office location, office phone number, e-mail, and office hours*. In the United States the way you present your name is important. If you write it as Professor Jones, the students will call you Professor Jones. If you write Carol or John, they will call you Carol or John. On the other hand, in New Zealand first names are used, while Germans are quite formal in the use of titles. You need to select your office hours before the class starts. Try to choose office hours that will be available to most students. If you welcome cell phone calls, give your cell phone number. If you don't want to be called on your cell phone, don't give your cell phone number! If e-mail is encouraged—and we think it should be—give your e-mail address. Ask the students to list the course number in the subject line so that you can quickly identify e-mail from your students.
3. *TA names, office hours, and location of their office hours*. Give the students the TAs' e-mails, but do not give the students the location of the TAs' labs. Introduce the TAs if they are present.
4. *Prerequisites*. Discuss how important these prerequisites are. Will you accept an F or a D or an incomplete in a prerequisite course? (Check your department's policy ahead of time.)
5. *Textbook*. Discuss any other supplementary material that the students should buy or that is available in the library. Pass out or post on the web a reading list if you use one.
6. *Tentative course outline*. Discuss the course outline and note the dates of tests and due dates of major projects. The earlier you give this information to the students, the fewer problems you will have with conflicts. Note: the course outline should *always* be labeled TENTATIVE. Labeling the outline as tentative gives you the option to later change dates if necessary.
7. *Teaching method and expectations of the students*. If 99% of the students' courses have been lectures and you will lecture, this can be very brief. If your course will be different, added discussion will be valuable.
8. *Grading scheme*. If you don't discuss the grading scheme, the students will ask about it. Be prepared for a question on extra credit.
9. *Seating arrangements and names*. If there is to be a seating chart, describe how it will be set up. Start learning student names unless there will be a large turnover the first week. Seating is not discussed at the beginning of the period since not everyone will be on time. If it is important to you that the students know that you care about them as individuals, then you *must* learn their names fairly quickly. Some teachers memorize the seating chart, others use photographs of students, some call the roll the first few weeks, and some ask questions using the class list. If discussion or group work will be important, you may want to use some method which

introduces students to each other. Various types of "name games" can be used to do this. Students can introduce themselves or others. Many students will appreciate a copy of the class roster.

10. *General discipline and classroom incivility policies*. Always enter the class with a positive attitude toward your students (see Chapter 12). However, it's likely that one or two students may pose problems, so briefly discuss the rules the class must live by. What is the policy about cheating, being late, being absent, cell phones, photographing the white board, surfing the web, reading a newspaper, or sleeping in class? What will your policy on makeup exams be? Be sure that your policies do not conflict with university and departmental policies.
11. *Assignments*. Explain the importance of class assignments and grading procedures. Explain your policy on late assignments. Be clear on the policy towards student collaboration on assignments (we encourage student collaboration, but some faculty are adamantly opposed to student collaboration).
12. *Honor code policy*. If your school has an honor code, discuss it.
13. *Extra credit policy*. If extra credit will not be allowed, state this clearly. If extra credit will be allowed, explain what is acceptable and when it is due. Of course, to be fair opportunities for extra credit have to be available to all students. Thus, extra credit after grades are posted must not be allowed.

Ask the class if there are any questions about course structure and policies—be sure to give them sufficient time to formulate questions and respond.

Some professors dismiss the students at this point, but we believe this is a mistake. Start teaching. Send the message that you mean business. The students will not be ready to start business, but they are never ready until you get them started. Use the remaining fifteen to thirty minutes for lecture, discussion, or whatever teaching method you intend to use. What content should be covered? One excellent method that will help motivate many students is to explain the importance and relevance of the material while presenting an overview of the course. Alternately, review a previous course that is an important prerequisite for the course. A third possibility is to start the first lesson. Regardless of the content, present it with enthusiasm and a sense of excitement so that the students will know that you consider the material to be important. Leave enough time for a short summary.

Finally, give the first homework assignment. At the very least the students should start reading. You know that they will not be very busy with homework the first week, and you want them to take your course at least as seriously as the competition. Pass out a sheet with the homework assignment on it. There will be fewer misunderstandings about what is due when. We post all assignments on the web, but it is best to also hand out hard copies of the first assignment. This completes the first class. Tell the students you will see them next class and signal that class has ended. A clear signal, such as picking up your books or saying goodbye, will be useful throughout the semester.

If you don't like housekeeping, there are other ways to start the first class. In an elective the first class period can be used to develop a course outline with the students' input. A test on prerequisite material can be given, but this will be unpopular and probably won't be extremely valid since no one has reviewed for it. The students can be given a problem which they will be able to solve at the end of the course, and they can be asked to work on it in teams.

This works if the importance of the problem is clear. If the course has a major project, you can introduce that project. In electives students can be required to write and turn in a paragraph on why they are taking the course. Your creativity can guide you to other possibilities.

Your attitude toward teaching is very important. If you are enthusiastic and look forward to the class, then the students will tend to do the same. If you have the attitude that it is your job to help students learn and earn a good grade, then you've taken a big step toward building rapport.

3.5. THE SECOND CLASS

The second class is surprisingly important. Many students consider it the first "real" class of the semester, so it sets the tone. Thus, it is very important for you to be well prepared for it. "Winging it" is always a mistake, and can be a disaster if done while you are still setting the course tone and student expectations. Enter the class with a sense of excitement and be enthusiastic. Avoid scheduling trips the first week of the term so that you can meet your classes.

Classes should always be started slowly so that students can switch gears and start thinking about this class. For starting this and other classes you might:

- Collect homework.
- Practice the names of students.
- Review the previous class.
- Add a bit of humor, if you can do so naturally.
- Show a cartoon related to the day's subject. A little entertainment before the class starts will not detract from the seriousness of your message.
- Have students make announcements from student organizations.
- Answer student questions from previous classes, reading, or homework.
- Mention a current event that relates to the class. Examples are a strike at a plant, the sale of sensitive computer parts to unfriendly countries, a new automotive design, an explosion and fire at a chemical plant, or a nuclear protest. Be sure to explicitly relate the event to the class.

A slow start is important, but these activities should last only a few minutes. Don't allow the students to lead you off on extensive tangents. During the remainder of the class cover the content listed in the course outline using the teaching method of your choice. It is very important in the second class to include lecture breaks and work hard at getting the students to be active since you are setting the tone for the rest of the semester (see Chapters 7 and 15 for a discussion of why students should be active). Toward the end of the period set aside time for student questions. Then summarize what has been covered in class. Pass out the homework and reading assignments or remind the class that the assignments are posted on the web. Remind students of your office hours and invite them to stop in and see you. If you want to be sure students know where your office is, you can require that the first homework assignment be handed in at your office. Ask anyone who missed the first class period to see you after class. Bring a few extra copies of the syllabus and other handouts for these students. Dismiss the class slightly before or at the ending time.

In general, it is useful for you to leave the classroom very slowly. Give students time to ask you questions. Many of these questions could have been asked during class. Answer them, but encourage students to ask similar questions in class next time. Most students need a good deal of encouragement to ask questions. Some student questions pertain only to a particular student and should be handled privately.

3.6. THE REST OF THE SEMESTER

With the semester under way, classes develop a routine punctuated by tests and large projects. You prepare for class, develop homework assignments and tests, present lectures or use another teaching method, grade or arrange for grading of homework and tests, have office hours, and deal with any problems that may arise. Then at the end of the semester you assign course grades, post them on the secure learning management system, and run off to a meeting or vacation. This appears straightforward, but conceals many issues.

If you are lecturing, you will need to prepare each lecture before class. The way you go about this often requires a little experimentation to obtain a feel for how to proceed. Do you need to write everything out, or are just a few notes sufficient? Can you accurately reproduce equations without notes? Are your presentations clearer when you use PowerPoint, a document projector, or a whiteboard? How much material can you comfortably cover in a class period? What is a good balance between theory and examples? Students always want more examples. How closely should the lectures follow the textbook? Students will complain if you follow the textbook too closely, and they will complain if you don't! What material is important and should be emphasized? Every textbook (including this one) has both trivial material and material which is becoming obsolete. Weed this material out.

To keep students actively involved with the material, have them take notes, ask and answer questions, discuss the material, work in groups, write short summaries of the lecture, solve problems at the board or at their desks, hunt for "mistakes" made by you, and so forth. *Active learners learn better*. Encourage questions by allowing time for them, acknowledging the student by name, repeating the question so that everyone can hear it, and then answering it as appropriate. If the question will be covered later in the lecture, you can ask the student to wait.

How should homework assignments be distributed throughout the semester? How long should problems be and how many problems should there be in each assignment? Should homework problems be done solo or should you encourage group effort? Do all problems have to be turned in and graded? Should a particular format be required? How do you or a TA grade a large number of homework problems? There is no one set of correct answers for these questions, but if you want your students to spread their efforts throughout the semester, you must spread homework and quizzes throughout the semester. Students generally consider quizzes and tests the most important part of a course. What material do you test on? There should be a correspondence between course objectives and the tests. Testing for memory is easier than testing for problem-solving skills, but probably is much less important. If you want students to be able to solve problems, testing must include problem solving.

The methods used in testing must also be examined. How many quizzes and tests should you give? How much should they be worth? How many problems should be on each quiz or test? Is it acceptable to use multiple-choice questions? Students appreciate help sessions before tests. Should you have them? If so, who should lead them, and when and where? Do you want to give partial credit? If so, how do you decide how much credit to give? Tests should be graded rapidly and as fairly as possible. In an ideal class graded tests would be returned before the students leave the classroom. In practice, returning graded tests during the next class period is considered fast. Go over the solutions when the tests are returned. Students do prepare for tests. Unfortunately, many students stop work on an area once the test is over. How do you get students to learn from their mistakes on tests? Since you will get requests for regrades, develop a regrade policy ahead of time. Do you want to give a final? Finals provoke a great deal of anxiety, but they also force students to review the entire semester and to some extent integrate the material they have learned.

How do you establish and maintain rapport with students? The best teachers have good rapport with their students even in large classes (e.g., Lowman, 1995). Students prefer professors who are enthusiastic, accessible, care about them as individuals, and are fair. Your challenge is to establish rapport while maintaining some professional distance so that evaluations of the students are fair. The goal is to develop a cooperative atmosphere where you and the students work together to maximize learning.

Office hours give students the chance to ask questions and to get additional help when they need it. Both you and the TA, if you have one, should have office hours. Some students want to talk to you solely, while others are scared to death of you. Office hours give you feedback on what the students do not understand and on what problems they cannot do. Keep your office hours or tell the students in advance when you will be out of town. Getting students to use office hours is often difficult. Continual encouragement and an open and friendly demeanor help. When students do show up for office hours, what is the best way to help them? How can you avoid spoon-feeding them and challenge them to extend themselves and do better than they think they can? What do you do to help a student who is trying but is absolutely, totally lost? Should the TA be trained in tutoring skills? Tutoring and advising are discussed in Chapter 10.

Since students forget details like office hours, before the first test remind them of your office hours and of the TA's office hours. Periodically send the students e-mails (but not everyone reads their e-mail) or text messages or tweets to remind them of office hours, homework due dates, and tests. Students will start to use office hours just before the first test or big project. Be prepared for an onslaught of students and consider how you will handle groups of students. Consider scheduling an optional help session before tests.

It is highly likely that you will slowly fall behind and material that should have been covered on Monday won't be covered until Friday. It is important to know why this happens so that the next time it won't. Write yourself notes on a copy of the course outline that explain what took extra time. Now you know what to do the next time, but what do you do now to cover all the material? If you haven't built an extra period into your course outline, the best solution is to skip some material. Do NOT speed up and try to cover all the material at a very fast pace. Look at the rest of the semester and decide what to delete. What if you get to the end of the syllabus and the semester is not over? Don't worry; this very seldom happens.

Throughout the semester you may have to deal with discipline problems. Student problems can range from the mildly annoying to the downright dangerous. The most common problems involve chronically late or absent students and passively disruptive students. If lateness bothers you, talk to chronically late students privately. They may have a legitimate reason for being late. However, in all cases start the class on time and do not backtrack for late-comers. Point out to chronically absent students that there is a reasonably strong positive correlation between attendance in class and grades. These students are also most likely to turn in homework and projects late and to be late for or miss a test. Passively disruptive students include those who talk, sleep, play video games, wear headphones, or surf the web in class. A useful instruction for the latter is "Please close your laptops." Include detailed policies in the syllabus about all these issues. Remember that the lack of a policy or ignoring these disruptions is also a policy (see Chapter 12). Since most of the students in the course do not appreciate distractions, you can enlist them to help curb the disruptions. Early in the semester, such as after the first test, hand out 3×5 cards and ask the students to answer the following: What can the professor or TA do to help you learn? Some students will mention stopping the disruptions. When you present the results, note this and start asking the disrupters to cease their disruptive behavior.

As the semester nears the end, you will want to know how well you have done from the students' viewpoint. Ask. Many universities have very elaborate arrangements for evaluating teaching, and some department heads require faculty to have their courses evaluated. If a mechanism does not exist, you can still ask the students for comments on the strengths and weaknesses of the course. The many factors which affect students' evaluation of teaching are discussed in Chapter 16.

How do you assign grades? If you have given the students a detailed breakdown of grades, you will need to follow that procedure; however, few students will complain if the scale is made easier. Several schemes for assigning grades are discussed in Chapter 11.

Throughout the first year new professors will have many questions about teaching. Talk to other professors—many of them. Since there is no single method of good teaching, you will get varied and occasionally contradictory responses. Sort through these responses and adopt those that fit you. Talk to kindred spirits about teaching on a regular basis. If you feel comfortable taking the risk, invite another professor or a representative from the teaching improvement center into your classroom to provide feedback. Exploring teaching issues with other professors will help you to learn to teach better and more efficiently, and it will help you maintain your sanity during a very busy first year.

This outline of what a professor does to design and teach a course shows that new professors are very busy their first few semesters. These are also the semesters when you want to start your research program. What really needs to be done? How do you get everything done? The first question is discussed in Chapter 17, while the second was essentially the topic of Chapter 2.

3.7. THE NEW FACULTY MEMBER EXPERIENCE

Most new faculty members feel unprepared to teach (usually a realistic appraisal) and are emotionally drained by the experience. For most, learning to teach is on-the-job training (OJT), which is strongly motivating but is not the best way to learn. New faculty usually over-prepare and may spend as much as thirty-five hours per week preparing for one course (Turner and Boice, 1989). This huge time commitment can be reduced by learning how to teach before teaching the first class. Invariably, new faculty members would like more advice about teaching and handling problem students (Boice, 2000).

Turner and Boice (1989, p. 52) report on three major problems for new faculty.

1. "Adapting to the appropriate pace and level of difficulty for the students." New professors have forgotten what it is like to learn material for the first time, and they invariably go too fast and are too theoretical. The lower the level of the students, the more likely this is to occur. Since material that appears easy to you may be very difficult for students (see Chapters 14 and 15 for reasons), never tell the students the material is easy.
2. "Feeling professionally overspecialized, while not having a well-rounded knowledge of their discipline." New faculty members often teach undergraduate courses which have little in common with their PhD research. Although they may have studied the material as an undergraduate, they are rusty. In addition, a typical new engineering professor has had little or no industrial experience and is not sure what the students will use in an industrial career.
3. "Having trouble establishing an appropriate professional demeanor in their relationships with students." New professors are asked to make the transition from student to faculty essentially overnight and often are not much older than their students. They must develop a professional demeanor that will allow them to effectively teach and grade both students they like and those they don't. It takes time to learn the proper distance between oneself and students. An additional problem of many new faculty members is a fear of not knowing all the answers. It is OK to tell students that you don't know the answer to a question but that you will find out. It is also OK, and actually helps to build rapport, to admit mistakes to the class.

"Early in their careers, faculty often find the challenges of academia too great for their skill levels. This can be particularly true in areas that professors are not trained for, such as teaching and advising" (Wankat, 2002, p. 6). In addition to teaching, new faculty have to start a research program, write proposals, learn the rules of a new institution, and adjust to a new city. There is also a psychological adjustment in becoming a professor instead of being a student. Part of this adjustment is deciding what you want students to call you. Many European countries are very formal and students address professors as Professor Smith. New Zealand, on the other hand, is very informal and students will call you by your first name. The US is in between and students will call you Professor Smith or Jim depending on which one you request. If you write "Prof. Smith" on the board that will be your name, while if you write "Jim Smith" many students will call you "Jim." Discuss this issue with your mentor before the first class.

It is very useful to have a mentor who knows many of the unwritten rules (Wankat, 2002). Mentoring works best when the procedure is formalized. Some universities use team teaching of courses to help new faculty. Formal development programs also work if new professors use them (Boice, 2000; Felder et al., 2011; Menges and Associates, 1999).

3.8. CHAPTER COMMENTS

The most common method of designing a course and a curriculum in engineering education is to put all the fundamentals first. Once these have been covered, the course or curriculum can proceed to the practical and interesting real-life problems. This approach appears rational but ignores motivation. Most people learn best when they know why they need to learn something. Thus, considering some practical, real-life problems early can help students significantly. This is one reason why cooperative education (alternating work and school periods) works well. This chapter discusses a real problem before you have all the information required to solve it.

Although this chapter purposely raises more questions than it answers, clearly spelling out what needs to be done for a class should be helpful to new professors, and we wanted to provide a chapter that would be immediately useful. One potential problem with enumerating tasks is that they assume a greater importance than attitudes. It is often the teacher's excitement, enthusiasm, and caring for the student which catch hold of students and fire them up for future work in the discipline. You may be able to do an adequate job as a teacher by just going through the motions, but for excellence you must do more.

Since many professors never ask themselves many of the questions asked in this chapter, one can obviously teach without understanding the process. Instead, the professor mimics former professors. Although strongly discouraged in research, mimicry or plagiarism is encouraged in teaching. Perhaps this observation helps explain why many schools value research more than teaching in their promotion policies.

If you want to read alternate approaches to preparing for your first course, try Barrett (2012), Filene (2005), Grunert O'Brien, Millis, & Cohen, (2008), Lieberg (2008), or Svinicki and McKeachie (2014).

HOMEWORK

1. Look through the undergraduate and graduate courses offered in your department. Classify each course using the scheme in Section 3.1. If there are some courses which do not fit the classification scheme, develop new classification categories for these courses.
2. What are some sources of information to help you estimate how much material can be covered in one semester?
3. Discuss additional reasons why it is a good idea to learn the names of students.
4. Class size is an important consideration in how you teach a course. List some of the things which are affected by class size.
5. Should you use a seating chart? It seems like a high school practice, but it is almost necessary for large classes if you want to learn names. Discuss this issue. Think of alternatives.
6. Brainstorm alternative ways to start the first class. List at least five additional ways.
7. How do you decide what to cover in a course that has never been taught at your school? Brainstorm at least five methods for developing ideas.
8. Is it a bad idea to tell the class that the textbook is a poor book? Explain your answer.
9. What are the concerns in teaching a student whom you instinctively like or dislike?

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CHAPTER 4

OBJECTIVES, TEXTBOOKS AND ACCREDITATION

What content to cover in a course is obviously a critical question for required courses that are prerequisites for other courses. We will discuss setting goals and objectives for a course, taxonomies of knowledge, the interaction between teaching styles and objectives, development of the content of a course, textbooks, and finally accreditation.

4.1. SUMMARY AND OBJECTIVES

After reading this chapter, you should be able to:

- Write objectives at specified levels of both the cognitive and the affective taxonomies.
- Develop a teaching approach to satisfy a particular objective.
- Decide whether to use a textbook in a course and select an appropriate textbook.
- List and discuss the requirements for accreditation of an undergraduate engineering program.

4.2. COURSE GOALS AND OBJECTIVES

Goals are the broad final results for a course. Usually they are stated in broad, general terms. In a thermodynamics course one's goals might be that students should be able to:

- Solve problems using the first law.
- Solve problems requiring use of the second law.
- Understand the limitations of thermodynamics.
- Appreciate the power and beauty of thermodynamics.

Content comes first. Engineering education is centered on content, and goals and objectives should focus on it (Plants, 1972). General goals such as these are nonspecific and often fairly easy to agree upon. However, goals are not specific enough to be useful in an operational sense except as an overall guide for a course. They are helpful to the department in designing the curriculum, to the professor in delineating the boundaries of the class, and to students (particularly intuitive and global learners) in seeing where the class is going. For example, if the department can agree that classical thermodynamics is the goal of the course, then you know that you are not expected to cover statistical or irreversible thermodynamics, and professors of follow-up courses will know that students will not have a background in these subjects. Clearly, this also implies a certain amount of communication and collegiality, which does not exist in all departments.

More specific *learning or behavioral objectives* are useful to guide both you and the students in exactly what they will learn, feel, and be able to do after each section of the course is completed (Besterfield-Sacre et al., 2000; Davis, 2009; Felder and Brent, 2003; Hanna and Cashin, 1987; Stice, 1976). A behavioral or learning objective states explicitly:

1. What the student is to do (i.e., the behavior), using an action verb.
2. The conditions under which the behavior is to be displayed.
3. The level of achievement expected.

Writing a few learning objectives for a class forces you to think about observable behavior (how will you know the student has learned?), conditions, and level of performance. However, few engineering professors write out complete behavioral objectives for all their classes. Here is an example of a cumbersome behavioral objective for a thermodynamics course:

> The student will be able to write down on a piece of paper the analysis to determine the new Rankine cycle performance when the maximum cycle temperature and pressure are changed. This will be done in a timed fifteen-minute in-class quiz, and the student is expected to obtain the correct answer within one percent.

Professors who use objectives invariably use a shortened version. In this form the previous objective becomes: Analyze the effect of maximum cycle temperature and pressure on the performance of a Rankine cycle.

This form is easier to write, focuses on content, and is more likely to be read by students. Behavioral objectives are usually written in the form of the minimal essential objective and focus on relatively low-level skills since such skills are easiest to measure. For higher-level skills behavioral indicators of achievement without minimum standards are more appropriate (Hanna and Cashin, 1987). For these objectives, student behaviors are illustrations only. Minimum standards are not given since students are encouraged to do the best they can. Conditions for performance are explicitly stated, but this may be done for an entire set of objectives and may be considered to be understood. A set of content-oriented related examples for a thermodynamics course is given in Table 4-1. Note that action verbs such as write, describe, solve, develop, determine, judge, evaluate, search, and select are used. Do NOT use verbs such as *know, learn* and *understand* because these verbs are not visible behavior (Felder and Brent, 1997). How would you know, for example, that a student "understands?" Felder and Brent (2003) give examples with emphasis on accreditation.

Objectives clarify the important content and ABET outcomes (discussed in Section 4.7) to be covered in readings, lectures, homework, and tests. If material is not important enough to have an objective, then it should be omitted. When developing tests, the professor can look at the list of objectives and check that the most important are included in the test questions (see Chapter 11).

Objectives should be shared so that students know what material to study and what material they will be tested on (Stice, 1976). Students should also be explicitly told if other skills, such as those involving a computer or communication, will be required. And they should know if they are expected to become broadly educated in the field and be able to do more than just solve problems. Examples of both these areas are included in the set of thermodynamics objectives. These objectives are written at several different levels. It is important to ensure that the course objectives and hence readings, lectures, homework, and tests cover the range of levels desired. The appropriate levels and types of objectives are included in taxonomies.

Note: ABET (Section 4.7) has invented their own nomenclature. What most of the educational world calls objectives, ABET calls outcomes. ABET reserved objectives for what graduates were expected to be able to do a few years after graduation.

4.3. TAXONOMIES OR DOMAINS OF KNOWLEDGE

Taxonomies of educational objectives were created by two significant committee efforts in the 1950s and early 1960s. The taxonomy in the cognitive domain (Bloom et al., 1956), which includes knowledge, intellectual abilities and intellectual skills, has been widely adopted, whereas the taxonomy in the affective domain (Krathwohl et al., 1964), which includes interest, attitudes, and values, has had less influence. A third domain is the psychomotor, manipulative, or motor skills area. A problem-solving taxonomy has also been developed by Plants et al. (1980). These taxonomies are discussed in the following four sections. Bloom's taxonomy has been revisited by Anderson and Krathwohl (2001) and many commentators prefer this version.

Table 4-1. Examples of Thermodynamics Objectives

1. The student can write the first and second laws.
2. The student can describe the first and second laws in his or her own language. (That is, describe these laws to the student's grandmother.)
3. The student can solve simple single-answer problems using the first law.
4. The student can solve problems requiring both the first and second laws.
5. Given the characteristics of a standard compressor, the student can develop schemes to compress a large amount of gas to a high pressure where both the amount of gas and the required pressure increase are larger than a single compressor can handle.
6. The student can determine and describe second law fallacies in proposed power cycles.
7. The student can judge when classical thermodynamics is not the appropriate analysis tool.
8. The student can find and correct errors in his or her own solutions and in those of others.
9. The student can search appropriate data bases and the literature to find required thermodynamic data, and if the data are not available the student can select appropriate procedures and predict the values of the data.
10. Since one of the goals of this course is to help students become broadly educated, the student can appreciate the beauty of classical thermodynamics and can briefly outline the history of the field.

4.3.1. Cognitive Domain

Since the cognitive domain is involved with thinking, knowledge, and the application of knowledge, it is the domain of most interest to engineering educators. Bloom et al. (1956) divided the domain into six major levels and each level into further subdivisions. The six major divisions appear to be sufficient for the purposes of engineering education.

1. *Knowledge*. Knowledge consists of facts, conventions, definitions, jargon, technical terms, classifications, categories, and criteria. It also consists of the ability to recall methodology and procedures, abstractions, principles, and theories. Knowledge is necessary but not sufficient for solving problems. Examples of knowledge that might be required include knowing the values of e and π, knowing the sign conventions for heat and work in an energy balance, knowing the definition of irreversible work, knowing what a quark is, being able to list the six areas of the taxonomy of educational objectives, defining the scientific method, and recalling the Navier-Stokes or Maxwell equations. However, tests may contain too many knowledge level questions because it is very easy to generate test questions, particularly multiple-choice questions, at this level. The ability to answer these questions correlates with a student's memorization skills but not with problem-solving skills. In some areas of science such as biology, students are expected to memorize a large body of knowledge, but this is unusual in engineering. The first objective in Table 4-1 is an example of a knowledge objective.
2. *Comprehension*. Comprehension is the ability to understand or grasp the meaning of material, but not necessarily to solve problems or relate it to other material. An individual who comprehends something can paraphrase it without using jargon. The information can be interpreted, as in the interpretation of experimental data, or trends and tendencies can be extended or extrapolated. Comprehension is a higher-order skill than knowledge, but knowledge is required for comprehension. Testing for comprehension includes essay questions, the interpretation of paragraphs or data (this can be done with multiple choice questions) or oral exams. The second objective in Table 4-1 is an example of an objective at the comprehension level. A warning: engineering and science students can and often will skip the comprehension step and solve problems in the application and analysis steps (Mazur, 1997).
3. *Application*. Application is the use of abstract ideas in particular concrete situations. Many straightforward engineering homework problems with a single solution and a single part fit into this level. Application in engineering usually requires remembering and applying technical ideas, principles, and theories. Examples include determining the pressure for an ideal gas, the cost of a particular type of equipment, the flow in a simple pipe, the deviation of a beam to a load, and the voltage drop in a simple circuit. Objective 3 in Table 4-1 is an example.
4. *Analysis*. Analysis usually consists of breaking down a complex problem into parts and determining the connections and interactions between the different parts. Objective 4 in Table 4-1 is an example of an analysis objective since it requires breaking a more complex problem into parts and then determining the relationship between the parts. Many engineering problems fall into the analysis level because complicated engineering systems must be analyzed.

5. *Synthesis*. Synthesis involves taking many pieces and putting them together to make a new whole. A major part of engineering design involves synthesis. Grading can be a challenge because there is no longer a single correct answer. Many students, particularly at the lower levels in Perry's scheme of intellectual development (see Chapter 14), find synthesis difficult because the process is open-ended and there is no single answer. Synthesis should be incorporated into every course and not be delayed until the "capstone" senior design course. Objective 5 in Table 4-1 is an example of a synthesis problem for a thermodynamics course.
6. *Evaluation*. Evaluation requires judging a solution, process, design, report, material, and so forth. The judgment can be based on internal criteria. Is the solution logically correct? Is the solution free of mathematical errors? Is the report grammatically correct and easy to understand? Is the computer program documented properly? Objectives 6 and 8 in Table 4-1 are examples of objectives at the evaluation level which use internal criteria. Objective 7 is also an evaluation example that can be based on internal evidence but is easier to attain if external sources are also utilized. The external sources would be some knowledge of statistical thermodynamics and irreversible thermodynamics. In many engineering problems the evaluation requires external criteria such as an analysis of both economics and environmental impact. Objective 9 in Table 4-1 requests evaluation using external criteria, and it also requests analysis.

Bloom's taxonomy is a hierarchy. Knowledge, comprehension, application, and analysis are all required before one can properly do synthesis. It can be argued that in engineering, synthesis is a higher-order activity than evaluation, since evaluation is needed to determine which of many answers is optimal. Without getting into this argument, note that students need practice and feedback on all levels of the taxonomy to become proficient. Professors need to ensure that objectives, lectures, homework, and tests include examples and problems at all levels. Stice (1976) noted that when he classified the test questions in one of his classes he was horrified to find that almost all of them were in the three lowest levels of Bloom's taxonomy. Since students tend to learn what they are tested for, most of the students were not developing higher-level cognitive skills in this class. If the teaching style, homework, and test questions are suitably adjusted, students can be taught content at all levels of the taxonomy.

4.3.2. Affective Domain

The affective domain includes likes and dislikes, attitudes, value systems, and beliefs. Development of a taxonomy for the affective domain proceeded in a parallel but slower fashion than for the cognitive domain. There was overlap on the two development committees, and the logic in developing the taxonomies was similar. However, the taxonomy in the affective domain was much more difficult to develop because there is much less agreement on the hierarchical structure. Krathwohl et al. (1964) used the process of internalization to describe the hierarchical structure of learning and growth in the affective field. Internalization refers to inner growth as an individual adopts attitudes, principles, and codes to guide value judgments. The affective domain taxonomy has had considerably less influence in education than the cognitive domain taxonomy, particularly in engineering education. The five levels of the affective domain are (Kibler et al., 1970; Krathwohl et al., 1964):

1. *Receiving and attending*. Is the individual aware of a particular phenomenon or stimulus? Is he or she willing to receive the information or is it automatically rejected? Does the individual choose to pay attention to a particular stimulus? Information above the individual's level of intellectual development may not be attended to because it cannot be understood.
2. *Responding*. The individual is willing to respond to the information. This occurs first as passive compliance when someone else initiates the behavior. Then the individual becomes willing to respond on his or her own initiative. Finally, the response leads to personal satisfaction which will motivate the individual to make additional responses.
3. *Valuing*. The individual decides that an object, idea, or behavior has inherent worth. The individual first accepts the value, then prefers the value, and finally becomes committed to the value as a principle to guide behavior.
4. *Organization*. The individual needs to organize values into a system, determine how they interrelate, and establish a pecking order of values.
5. *Characterization by a value*. The individual's behavior becomes congruent with his or her value structure, and acts in a way that allows others to see his or her underlying values. Many modes of common speech point to people who are characterized by their values: "She is a caring person." "He always puts students first." "He is very up-front."

The affective domain has not been heavily studied or discussed in engineering education, yet engineering professors do have value goals for their students. They want them to be honest, hard-working, ethical individuals who study engineering because of an intrinsic desire for knowledge. Perhaps there would be a little more movement toward these goals if professors explicitly stated some of their expectations and objectives in this domain. One example is the use of an honor code. A second example is "the student will appreciate," which is at the level of valuing in the affective taxonomy, in objective 10 in Table 4-1. Unfortunately, measuring students' appreciation is difficult, and since "what gets measured is what gets improved" (National Academy Engineering, 2009) appreciation does not get improved.

4.3.3. Psychomotor Domain

The psychomotor domain includes motor skills, eye-hand coordination, fine and major muscle movements, speech, and so forth. The importance of this domain in engineering education has been continually decreasing as shop courses have been removed, digital meters have replaced analog meters and calculators replaced slide rules. Psychomotor skills are still useful in engineering education, particularly for graduate students doing experimental research. Examples include reading an oscilloscope, glassblowing, welding, turning a valve in the correct direction, soldering, titration, keyboarding, gestures while speaking, and proper speech.

The taxonomy in the psychomotor domain includes (Kibler et al., 1970):

1. Gross body movements.
2. Finely coordinated body movements.
3. Nonverbal communication behaviors.
4. Speech behaviors.

Finely coordinated body movements include keyboarding. Because of the importance of computers and calculators in the practice of engineering, this psychomotor skill has become more important than in the past. Nonverbal communication needs to be congruent with the spoken message. Individuals can be successful engineers with speech handicaps. However, the ability to speak clearly and distinctly and to project one's voice is a distinct aid to communication. In addition, communication can be enhanced by coordinating facial expressions, body movement, gestures, and verbal messages (see Chapter 10). Professors who desire to become outstanding lecturers need to develop their skills in speech behaviors (see Chapter 6).

4.3.4. Problem-Solving Taxonomy

A problem solving taxonomy was developed by Plants et al. (1980). This taxonomy was published in the engineering education literature but has not been as widely distributed or adopted as the other taxonomies. However, because of the importance of problem solving in engineering education, it can be useful. Applications of the problem-solving taxonomy to engineering education are discussed in Chapter 5 and by Plants (1989). The five levels of the taxonomy are briefly discussed below.

1. *Routines*. Routines are operations or algorithms that can be done without making decisions. Many mathematical operations such as solution of a quadratic equation, evaluation of an integral, and long division are routines. In Bloom's taxonomy these would be considered application-level problems. Students consider these "plug-and-chug" problems.
2. *Diagnosis*. Diagnosis is selection of the correct routine or the correct way to use a routine. For example, many formulas can be used to determine the stress on a beam, and diagnosis is selection of the correct procedure. For complex integrations, integration by parts can be done in several different ways. Selecting the appropriate way to do the integration by parts involves diagnosis. This level overlaps with the application and analysis levels in Bloom's taxonomy.
3. *Strategy*. Strategy is the choice of routines and the order in which to apply them when a variety of routines can be used correctly to solve problems. Strategy is part of the analysis and evaluation levels of Bloom's taxonomy. The strategy of problem solving and how to teach it are the major topics of Chapter 5.
4. *Interpretation*. Interpretation involves reducing a real-world problem to one which can be solved. This may involve assumptions and interpretations to obtain data in a useful form. Interpretation is also concerned with use of the problem solution in the real world.
5. *Generation*. Generation is the development of routines which are new to the user. This may involve merely stringing together known routines into a new pattern. It may also involve creativity (see Chapter 5) in that the new routine is not obvious from the known information.

4.4. THE INTERACTION OF TEACHING STYLES AND OBJECTIVES

To meet any of the objectives (including affective), students must have the opportunity to practice and receive feedback. If you want them to meet certain objectives, share these objectives with them and test for the objectives. Students will work to learn the stated objectives in the course. If objectives are not stated or are unclear, they will work to learn what they think you want. Remove the mystery and tell them what you want with clear objectives.

The importance of clear objectives is highlighted by research on teaching styles and student learning (Taveggia and Hedley, 1972). Student learning of subject matter content as measured by course content examinations is essentially the same regardless of the teaching style (with the exception of mastery learning) as long as students are given clear, definite objectives and a list of materials for attaining the objectives. This applies to the knowledge, comprehension, application, and perhaps analysis levels, but not to synthesis, evaluation or problem solving.

Engineering courses focus on cognitive content objectives. Knowledge-level objectives and content are the easiest to learn and can be learned from well-written articles, books, and class notes. If the objectives are clear, students will memorize the material. For example, if students reading this book are told to learn the six levels of the cognitive domain, they will memorize them. Lecture can also be used for transmission of knowledge-level material, but it is less effective than written material except for clarifying questions. Comprehension is a higher level than knowledge, and more student activity is useful. Written material is useful, particularly if the student paraphrases the material or develops his or her own hierarchical structure. To be effective, lectures need to have discussion and/or questions so that students actively process the material. Discussion in groups can also be helpful for comprehension.

Applications in engineering usually mean problem solving. It is useful to show some solutions in class, but there is the danger that the solutions shown may be too neat and sterile since the professor has removed all the false starts and mistakes (see Chapter 5). Watching someone else solve problems does not make one a good problem solver: The student must solve problems. A good starting point is homework with prompt feedback and with the requirement that incorrect problems be reworked. Group problem solving both in and out of class is effective since the interactions help many students. Students who tutor and teach other students are highly likely to master application objectives since tutoring and teaching require one to structure the knowledge. Analysis objectives usually involve more complex, multi-step problems and can be taught by the same methods used for application.

To learn to do synthesis, one must do synthesis. This can be started in the first year engineering design courses. Group work can again be valuable since it helps motivate students and increases retention (Hewitt, 1991). Synthesis in upper-division classes often involves developing a new design, whether it is an integrated circuit, a chemical plant, a nuclear reactor, or a bridge. Creativity can be encouraged by providing computer tools that will do the routine calculations. The PMI approach (see Section 5.7.3) which finds pluses, minuses, and interesting aspects of the proposed solution is useful in encouraging students to be creative.

Evaluation is not something that only the professor should do. Students need to practice this skill since they will be expected to be able to evaluate as practicing engineers. You can demonstrate the skill in class, by having the students practice evaluation, and providing feedback on their evaluations. One way to do this is to show an incorrect solution. After giving the students a few minutes to study the solution, you can grade the solution while the students watch. The students can then be given several solutions to evaluate as homework. At least one of these solutions should be correct since part of evaluation involves recognizing correct solutions. The students' papers are then turned in and graded. A slight twist to this is to return student homework or tests with no marks and tell the student to evaluate and correct the paper before turning it in for a grade.

Engineering professors can help students to master objectives in the affective domain by sharing the explicit objectives with them in a positive fashion. For example, you might say, "Since you all expect to become practicing engineers, I expect you to demonstrate professional behavior and ethical standards in this class." This is preferable to saying, "If I catch any of you cheating I am going to prosecute you and force you out of engineering."

Short (and be sure they are short) "war stories" during lectures can help students socialize and internalize the engineering discipline (this socialization is usually a major unstated affective objective), but they need to be related to the topic covered in class that day. Engineering experience through co-op, internships, and summer jobs is an excellent way to socialize engineering students if the experience is positive. Enjoyment of the class is one of our affective objectives. A professor who is pleasant, greets students by name, and is both fair and reasonable is likely to have students who enjoy the class.

Psychomotor objectives require practice of the skills. Most of these can be done in laboratory, but the professor needs to be aware that students may need instruction in some simple manual manipulations. Groups are effective since one member of the group often already possesses the psychomotor skills. Few engineering professors are trained to work with students who have major deficits in the psychomotor area. Since psychomotor problems, particularly in speech, can cause both students and practicing engineers difficulties, engineering professors should know what resources are available for help.

4.5. DEVELOPING THE CONTENT OF THE COURSE

The content of each course is the topic of many faculty discussions. We do not intend to discuss disciplinary details. Instead, we will briefly explore some pedagogical details. In required courses the content must make the course fit into the curriculum.

Although there is never complete unanimity, most engineering departments generally agree on the content a student must study before graduation. This content must appear somewhere in the curriculum. Since required courses often serve as prerequisites for other courses, the prerequisite material must be covered. The only way to ensure that the expected content is covered is to communicate with other faculty. Discuss in detail what material the students have had in prerequisite courses and find out what they are capable of doing after they have passed the prerequisite courses. (Obviously, what a student can do is not the same as what the professor covered.) Discuss the outline with other faculty who have taught the course in the past or who might teach it in the future. Before making major course revisions or changing the textbook be sure that critical material is not deleted. Talk to engineers in industry to determine what they use. Unfortunately, some students will not use computers to solve problems unless required to do so. We believe that at least one course each year should require extensive computer calculation with spreadsheets, MATLAB, simulations, statistical packages, and so forth. The department faculty should decide what software will be used in a specified course.

Once the major content for the course has been outlined, look at the hierarchy of objectives you wish to cover. The time required for each topic depends on the depth of coverage in addition to the beginning knowledge of the students. A well-thought-out textbook will have done this, but you may disagree with some of the author's decisions. Plan the level of presentations considering the students' maturity (see Chapter 14). Then you can plan the major objectives for each lecture.

We suggest that the bulk of the course be developed for the sensing types and serial learners in the class (see Chapters 13 and 15). Following a logical development makes it much easier for these students to learn the material, and this sequence does not hamper the intuitive types and the global learners. Sensing types will appreciate examples and concrete applications. At the beginning and/or end of each class include the global picture for intuitive types and global learners. Intersperse theory with applications to keep both the intuitive and sensing types interested. Include visual material. Conscious use of a learning cycle (see Chapter 15) will increase student learning. This arrangement will ensure that every student has part of the course catered to his or her strengths, but that the student will also be encouraged to strengthen his or her weaknesses.

4.6. TEXTBOOKS

Textbooks (including electronic texts) are used in about 90% of college courses in the United States (Landrum et al., 2012). In the past many engineers kept their textbooks and used them as a primary reference for many years. Unfortunately, most students now sell their textbooks when the course is over. Useful discussions on textbook selection are included in Eble (1988), Lee et al. (2013), and Wankat (2002).

4.6.1. Should a Textbook Be Used?

A well-written textbook provides content at the appropriate level in a well-structured form with consistent nomenclature and includes appropriate learning aids such as example problems, objectives, figures, tables, and homework problems at a variety of levels of difficulty. However, a textbook usually provides only one viewpoint, may not include the content you want, may be out of date, may not be the ideal format for helping students learn to learn on their own, and the solution manuals for the problem sets may be readily available on the Internet.

Students in beginning courses rarely have the sophistication to wade through the research literature or to pick the gems from the dross of the Internet. Since basic knowledge is not changing rapidly, textbooks for beginning engineering courses do not become obsolete rapidly; and because of the numerous pressures to standardize lower division courses (e.g., transferring of credits, ABET requirements (Section 4.7), and movement of faculty between schools), textbooks which closely match the requirements of these courses are usually available. Thus, textbooks are usually used for required lower-division undergraduate courses. If an *appropriate* textbook is not available, a publish-on-demand textbook can be considered (see Section 4.6.3).

The situation is often different for undergraduate elective courses and courses at the graduate level. Since the market for specialized books is smaller than for required undergraduate courses, there will be fewer books to choose from and they will be expensive. Seniors and graduate students need less structure and can better cope with varying author styles and different nomenclatures. The original literature is more difficult to read since it was not written for students, but it is a good vehicle to help advanced students learn how to learn on their own. The original literature can often provide a sense of excitement missing from most textbooks. Thus, it may be appropriate to assign readings from the original literature.

Is the cost reasonable? Many engineering textbooks are not reasonably priced, and this may be a reason to use readings from the original literature. However, copyright law is in flux and professors need to be cautious when making a number of copies of copyrighted material for a class. Permission must be obtained from the copyright owners before making copies. However, assigning reading of E-journal articles that students access on their own is legal. "Fair use" allows use of copyrighted material in other reasonable educational activities. For example, showing copyrighted material during a lecture is allowed. See Section 3.3.7 for a more detailed discussion of fair use.

A good textbook can be a tremendous aid and save you a great deal of time if you use it. By developing the book for a course, the author has already done much of the organization and presentation of content for you. It is common for professors to assign reading an entire chapter and then skip a large portion. Students are adamant that they are busy and want to be told "exactly what to read" (Berry et al., 2011, p. 36). Although useful, books do limit what you can do in a class. Students won't mind if you occasionally require other readings. However, doing this extensively will annoy them and make them wonder why you have made them buy an expensive book and then never use it.

4.6.2. Textbook Selection

To some students the textbook is treated as if it contains **The Truth.** Perhaps this is a carryover from the monastic beginnings of universities where students studied "sacred texts" (Palmer, 1983). Because of this student devotion, textbook selection is important. An unnecessarily difficult textbook will discourage, excessive errors can lead to a loss of faith, and an obsolete textbook serves students poorly. How does one choose an *appropriate* textbook?

Parts of the Book Used by Students. What parts of the book will the students actually use? In beginning courses students often want and need the assistance in solving problems that a textbook with good example problems provides. Sensing students particularly appreciate detailed examples. The students also appreciate the collection of physical properties and formulas provided in the textbook. If you assign homework problems from the book, the students will also use the homework sections. Students would benefit from careful reading of the text, but most students do not do this (Lee et al., 2013). Although course grades are positively correlated with the percentage of the reading completed (Landrum et al., 2012), 25–30% of the students do not read the textbook or class notes (Heywood, 2005; Berry et al., 2011).

Content Coverage. Does the content coverage match the coverage in the course? A careful check of content versus your preferred course outline is necessary. Does the sequence of material make sense? Skipping around in the book is often confusing to students. Books that have light coverage of some topics may have to be supplemented with course notes and/or outside reading. If some topics are explained in insufficient detail, you may be able to compensate in lecture. And if the book has extra material that the course will not cover, you need to determine how easy it will be to skip sections. Some authors clearly state the prerequisite chapters for each chapter so that users know which sections can be skipped. Other authors provide supplemental sections of optional material. The most recent copyright date can tell if recent advances might be included, but not all authors of undergraduate textbooks are up-to-date with research. Read a few chapters to make sure the ideas are current and accurate.

While looking at the content, check for typographical errors and fundamental mistakes. Not all books are created equal with respect to accuracy. A convenient way of comparing a number of books is to check a few key items that you will cover in your course.

Example Problems. Are the example problems high quality? Examples need to be more than a collection of equations with numbers plugged in. Examples need to explain how problems are solved. Use of a common problem solving strategy (see Section 5.4) is helpful because the students soon understand the basic pattern. Typographical errors in example problems can be extremely confusing to students who have not yet learned how to evaluate the material for correctness. Such errors may also undermine the book's credibility with students.

Equations and Data. Are the necessary equations and physical constant data available and accurate? Equations and data need to be accurate with a limited number of typographical errors.

Cost. Cost is important to students and to the federal and many state governments (Berry et al., 2011). Although professors often ignore cost, they probably should include cost, and may be forced by state laws to include it, in their decision to adopt a textbook. Textbooks that are free on the Internet are very popular with students, and certainly should be considered if their coverage is close to course requirements.

Homework Problems. Homework problems should be clear and unambiguous. It is also helpful if the level of difficulty of the problems is indicated. Examine the solutions manual since it is a good guide to how carefully the homework problems have been crafted. The absence of a solutions manual may indicate that the author did not spend much time developing the homework problems. However, since most solution manuals are available online, professors will need to write some homework assignments.

Learning Friendly. Although you can assume that most authors of engineering textbooks understand the content, you cannot assume that they understand how students learn. Introductory textbooks should use an inductive approach starting with specifics and leading to generalities (See Section 15.3.1), and should be written in a concrete instead of an abstract style. Explicitly listing objectives is also helpful to tell students what they are expected to be able to do. The writing should be at a level appropriate for the students, and new jargon should be carefully defined. Figures and tables should be clearly labeled so that nothing needs to be assumed to understand them. Relatively short sections are easier for most students since there is a sense of accomplishment when each section is completed. Intuitive students may use the section headings and subheadings to obtain an overview of the chapter contents, so it is important that these give a true picture of the organization of the content. Books using a deductive approach or written in an abstract style with few examples may be appropriate for advanced-level classes where students are seeing the material for a second time.

Student Friendly. Is the book's organization student friendly? Robinson (1994), who assumed that students will read the textbook, states a student-friendly book will contain:

- *Objectives*
- *Questions* for the student
- *Transitions* between topic that show the relationships among the topics
- *Signals* (e.g., italics) that indicate the material is important.
- *Advance organizers* (e.g., an outline or flow sheet) to help provide the global picture.

E-books. The availability of an e-book is coupled with the cost criterion. According to the *Chronicle of Higher Education Almanac* (2013) over 89% of all students were satisfied or very satisfied with use of an e-book in a core course. Students who preferred an e-book listed the following items: easy search and reference, easy to carry around, costs less, available quicker, convenient, and interaction with content. Engineering students have different needs and may be less satisfied with e-books. Table 8-1 shows students' preferences for more e-book use.

Supplemental Material. Is there supplemental material that will be used? If you will be teaching a course that is not your major interest, a solutions manual that correctly solves problems will be helpful even if the students obtain solution manuals from the Internet. If the course is in your area of primary interest, you may choose not to use a solutions manual. Computer software bundled with the adoption of a textbook can be advantageous if the software is compatible with the school's computer system, but software increases the price of the book. Some engineering textbooks integrate software into the homework assignments and the teaching of the content. Some textbook's websites have additional useful material such as slides.

Permanence. Will the book be useful to the students in later courses or as a reference after they graduate? An excellent index is not necessary when a book is used as a textbook, but in the hard copy of a book it is essential for reference use (electronic copies can use the search engine available in the file format). Proper referencing of appropriate source materials is also important for reference use of the book. If students will keep the book for a long period, it needs to be printed on good quality paper and be durably bound. Note that e-books are usually active for only a relatively short period, so they and rentals will probably not be available for reuse. A laboratory workbook that will probably be discarded does not need this kind of quality.

Once the data has been gathered, how do you make the decision? Although a number of good decision making methods have been developed, our favorite is the Kepner-Tregoe (K-T) Decision Analysis (Fogler et al., 2013). To apply the K-T method to textbook selection one would

Table 4-2. Sample K-T Decision Analysis for Textbook Selection

MUST HAVE	Text 1	Text 2	Text 3
Appropriate coverage	Go	Go	Go
Example problems	Go	Go	Go
Solution manual	Go	Go	No Go
Electronic version	Go	Go	Go

WANTS		Text 1		Text 2		Text 3
	Weight	Rating	Score	Rating	Score	
Topic 1	6	8	48	7	42	**NO**
Topic 2	5	4	20	7	35	**GO**
Topic 3	2	10	20	2	4	
Quality soln manual	7	6	42	3	21	
Learning styles	6	4	24	4	24	
Cost	5	1	5	8	40	
Total			159		166	

first list the content areas and features (e.g., cost, examples, quality of hard copy, electronic copy available, and solution manual) that are useful in the course. These features are then classified as either *must have* or *wants.* The must have items are either present, Go, or not present, No Go. The want items are rated for each textbook and values are listed in a K-T table (see Table 4-2). Although not necessary, it is often useful to assign weights to each want item. Note in Table 4-2 that appropriate coverage and availability of a solution manual are must have items *and* the quality of the topic presentations and of the manual are ranked under wants (double ranking is not part of the original K-T method, but was added since it makes sense for this example). Accommodation of learning styles is discussed in Section 15.3.3. Cost is ranked inversely with lower cost books receiving a higher ranking. In this example, Text 3 is a No Go because there is no solution manual, and the cost rankings are the deciding factor in choosing Text 2.

Textbook adoptions should be considered to be tentative. After a semester's use, the book can be reevaluated. Ask the students for feedback on the book. Consider how well it worked on a line-by-line and day-by-day basis. If the book does not work out or a better book becomes available, you can switch.

4.6.3. Print-on-Demand and Publish-on-Demand Textbooks

Print-on-demand is currently common for books not expected to have large print runs. The text, tables and figures for the book are stored in an electronic file. After an order is registered, the electronic file is read to a rapid printer that prints the entire volume, which is then bound and sent to the purchaser. This publishing model reduces the expensive inventory of unsold books to essentially zero. Some publish-on-demand organizations, such as Lulu.com, allow self-publishing while others such as Springer use publish-on-demand mainly for out of print books. In addition to printing hard copies publishers often offer downloading of files from the web, which with some publishers is free.

The publish-on-demand textbook is an alternative for professors who want to customize the textbook so that students do not buy chapters they will not use. A large number of books and other resources are stored as electronic files. The user selects the parts wanted and the order in which they should appear. The computer software automatically renumbers all chapters, figure and table numbers, equation numbers, and so forth. The new book is printed in the desired order, and the books are bound and shipped to the school. The cost is proportional to the book size.

With publish-on-demand technology, chapters from different books and even chapters written by the professor can be included in the made-to-order book. The publisher (e.g., http://www.academicpub.com/) takes care of obtaining permissions and paying appropriate royalties and fees. Since professors customize the books, the actual number of pages each student purchases will be less and the cost will probably be less. However, there is likely to be a smaller market in used books since customized books are much less transferable from school to school. Thus, the publisher will probably sell more new copies.

However, this is still a relatively new technology and not all the problems have been resolved. The technology for ensuring that the nomenclatures of different chapters are compatible if the chapters are from different sources is still under development. Of course, there's no guarantee that a single author will be consistent in the use of nomenclature either. Content is available from a large number of publishers, but content from the largest publishers such as McGraw-Hill, Pearson, and Wiley may not be available except from that publisher. Acceptance by the professoriate and by students is also not assured.

4.6.4. Writing Textbooks

"There are bad texts—which someone else writes—good texts—which we write—and perfect texts—which we plan to write some day" (Eble, 1988). The motivation to write a textbook in engineering often arises from dissatisfaction with the available textbooks or the total unavailability of any textbook in a new field. Writing a textbook is difficult but rewarding. While writing the textbook, the professor is likely to be vitally interested in the class and will probably do a good job teaching the course. There is personal satisfaction from having done a difficult task well, a good textbook can help an engineering professor become well known, and a successful textbook can be financially rewarding. However, since 80% of the sales are from 20% of the books, many books make very little money (Burroughs, 1995).

The common wisdom is that engineering professors should wait to write a textbook until they have tenure. The professor should have several years of teaching experience, which will be helpful in writing the textbook, and should probably be an expert (see Section 5.3). Because of the period of time required, writing one is risky for an assistant professor. And, most importantly, since many promotion and tenure committees and many administrators at research universities do not look favorably on textbooks, they may not help an assistant professor be promoted (Burroughs, 1995).

Engineering professors are not trained in all the various aspects of writing textbooks, and a certain amount of on-the-job training takes place. Fortunately, successful authors enjoy writing about writing, and there are a variety of sources of advice for writing engineering textbooks (Beakley, 1988; Bird, 1983) and for writing general books (Lepionka, 2008; Wankat, 2002; Zerubavel, 1999). Lepionka (2008) discusses the pedagogical elements that will help students learn from your textbook. If you are thinking that you will have your lecture notes transcribed and that will give you a book, read Lepionka's (2008, p. 171) argument why converting lectures into books rarely works. I (PCW) tried starting with my lecture notes as a first draft for one chapter of my junior chemical engineering textbook, and then spent more time revising that chapter than any other.

New textbook authors should seriously consider joining the Text and Academic Author's Association (TAA, http://taaonline.net) and benefit from news and author assistance. Joining TAA is particularly helpful for learning about contracts and what publishers do, but, of course, it is not helpful for deciding upon appropriate content. A little knowledge (such as that a 15% royalty on a publisher's net receipts is common for college textbooks) is very helpful when a contract is negotiated. However, our advice to potential authors is simple. Do not write a book for the money—you can make more money consulting. The textbook market is in turmoil and companies are not confident that their business models are sustainable (Boroughs, 2010). The golden age (1960s to 1980s) of textbook writing, when engineering authors could confidently order a new Porsche if their book did well in securing adoptions, is over. However, if writing a book is the right thing to do for other reasons, do it. Signs that it is the right thing to do include:

- You've taught the course for several years, and the available books are not satisfactory.
- You *know* you can write a better book.

- You feel *compelled* to write a book.
- You have already written extensive supplemental handouts for the class.
- Students ask why you haven't written a book since they are sure you can do a better job.
- You have sufficient energy and time for another big project.

With appropriate changes in wording, the same signs apply to developing computer-aided instruction (Section 8.7), or an educational computer game (Section 8.5).

4.7. ACCREDITATION OF UNDERGRADUATE PROGRAMS

Author's Note. This section has been completely rewritten to match the current Engineering Accreditation Commission (EAC) of ABET (formerly the Accreditation Board for Engineering and Technology) accreditation policy EAC-2000. Since most engineering professors just refer to ABET and ABET-2000, we will do the same.

Most engineering programs in the United States are accredited by ABET. Accreditation allows graduates to take the appropriate examinations to become a professional engineer, makes the transfer of credits to other universities easier, makes it easier for graduates to get admitted into graduate school, and serves as a stamp of approval on the quality of the program. However, accreditation does put some constraints on undergraduate engineering programs. These constraints have been the focus of considerable debate since many engineering educators believe they stifle educational innovation.

ABET's policy is to accredit individual engineering or technology programs, not an entire school. It is not unusual to have both accredited and unaccredited programs at the same university. The unaccredited programs are not necessarily poorer; instead, they may represent innovative programs that do not fit within ABET's constraints.

4.7.1. The Accreditation Cycle

Universities request and pay for the costs of ABET accreditation. The ABET accreditation procedure starts with a letter to the dean who responds that reaccreditation is desired. The institution then develops very detailed self-studies for each program to be accredited. Both general information about the institution and detailed information on each accredited engineering program are prepared. The program self-study explains the program and details how the program meets the ABET criteria that are delineated below. Resumes for all faculty members in the programs and a syllabus for every course in the curriculum are included.

In the normal schedule the self-study is due in July, and a fall program visit is scheduled. A program must have at least one graduate before ABET will schedule a visit. Before the ABET visit each program sends ABET transcripts for recent graduates—ABET specifies how they are to be collected (e.g., ABET may ask for transcripts of the first six graduates with a last name beginning with K).

An ABET team, which consists of the team captain and one member for each program to be accredited, visits the school for three days. The team members speak with faculty and students; study course notebooks prepared by the faculty; investigate student transcripts; tour the facilities; interview selected professors, staff, students and administrators; and obtain answers to questions raised while reading the self-study. Accreditation visits are considered extremely important, and considerable time is spent preparing for them. The ultimate question the evaluator has to answer is, does the program satisfy the ABET criteria (Section 4.7.2)?

Accrediting teams write their report before leaving the campus. Many teams work with the institution to solve difficulties before they write their report. The accrediting team has several choices of outcome in their report. They can accredit the program for a full six-year term either with no difficulties or with a *concern* (this is a flag for the next visiting team to look at this issue). If there is a *weakness* (one or more criteria were not satisfied) accreditation can be for an interim three-year period with a report to justify three additional years, or accreditation can be for three years with both a report and an additional visit required before the next three years will be accredited. For unsatisfactory programs a *show cause* might be given. A *show cause* means that the school must show why ABET should not remove accreditation. Finally, the visiting team may decide not to accredit the program. Accreditation reports that give less than complete accreditation are often used to obtain needed additional resources from the university.

After the visit is over, the accreditation cycle is not finished. Institutions first have a week to correct errors in fact. After they receive the ABET draft report, they have 30 days to respond to any problems that were observed. Usually, the best response is to fix the problem. Based on this additional information, the original visiting team's report, and a comparison with other schools being evaluated, ABET makes a final decision that is conveyed to the institution in the summer. Since ours is a litigious society, negative ABET reports are often contested further.

4.7.2. ABET Criteria

The ABET criteria are laid out in an ABET publication (ABET, 2013) available free on their website, http://www.abet.org. The eight general criteria that apply to all engineering programs are outlined in Table 4-3. There are also program-specific criteria that apply to programs such

Table 4-3. Summary of ABET Criteria for Accreditation of Engineering Programs

Criterion 1. Students	Evaluate performance, monitor performance, and enforce policies.
Criterion 2. Program Objectives	Expectations for students a few years after graduation.
Criterion 3. Student Outcomes	What students will know and be able to do at graduation. See Table 4-4.
Criterion 4. Continuous Improvement	Process to assess and evaluate meeting outcomes, and to use results as input to improve.
Criterion 5. Curriculum	Subject areas appropriate for engineering. See Table 4-5.
Criterion 6. Faculty	Sufficient number and quality to properly run program.
Criterion 7. Facilities	Classrooms, offices, labs, library, and computer services support learning activities.
Criterion 8. Institutional Support	Support and leadership ensure program quality and continuity.

as mechanical or biomedical engineering. Criterion 1 refers to the program's policies with respect to students. The ABET evaluator tries to determine if the policies are applied fairly and uniformly. Each program must consult with its constituencies and determine appropriate program objectives (criterion 2). The objectives indicate what successful graduates will attain a few years after graduation.

For graduates to meet the objectives, a series of learning outcomes are specified in criterion 3. The eleven outcomes specified by ABET are given in Table 4-4. Five of the criteria refer to technical outcomes (criteria 3a, b, c, e, and k) and six refer to professional outcomes (criteria 3d, f, g, h, i, and j). One of the complaints about ABET-2000 is that there are too many outcomes and ABET gives no formal guidance as to which outcomes are more important. There is widespread support for professional criteria 3d (teams) and 3g (communication). In their brilliant Chapter 16 (a must read for all professors) Sheppard et al. (2009) describe the need to instill core ethical and professional values (3f) in students—and this includes the need for ethical behavior—a topic curiously missing from criterion 3f. However, since Loui (2005, p. 388) found that "a course in engineering ethics reinforces the students' previous inclinations to act morally," there probably is an effect on behavior. Criterion 3i is widely believed to be important, but how to assess "a recognition" is not clear. The importance of learning after graduation is reinforced by studies of graduates that show they need several years of on the job education before they are ready to engineer (Williams et al., 2014). Professional criteria 3h and 3j are considered by practicing engineers one to ten years after graduation to be less important (Passow, 2012) and have significantly less faculty support than the other criteria (Lattuca et al., 2006). Unfortunately, disconnects over globalization issues exist between new engineers and most professors and many experienced commentators who consider criterion 3h to be critically important (National Academy of Engineering, 2005; Williams et al., 2014). Some ABET program evaluators privately state that as long as a program does anything to teach and assess criteria 3h, 3i and 3j, they accept it.

Table 4-4. ABET Student Outcomes (Criterion 3)

(a) an ability to apply knowledge of mathematics, science, and engineering
(b) an ability to design and conduct experiments, as well as to analyze and interpret data
(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
(d) an ability to function on multidisciplinary teams
(e) an ability to identify, formulate, and solve engineering problems
(f) an understanding of professional and ethical responsibility
(g) an ability to communicate effectively
(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
(i) a recognition of the need for, and an ability to engage in life-long learning
(j) a knowledge of contemporary issues
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice."
(l, m,) any additional outcomes added by the program.

In the early years of ABET-2000, program examiners were most interested in the methods used to assess the outcomes. ABET requires direct assessment of how much the students have learned either by the professor, by a visiting committee, or with a national examination such as the Fundamentals of Engineering examination. ABET allows direct assessment data to be supplemented with indirect assessments such as student interviews or surveys about the quality of their education. Initially, most engineering professors strongly resisted assessment because they thought it would be too time-consuming and they were not used to being told what to do.

After realizing that direct instructor assessment of student outcomes can require little additional time for the technical criteria, many professors acquiesced (Briedis, 2008). The trick for easy direct assessment of technical outcomes is to first define the course outcomes (Besterfield-Sacre, 2000; Felder and Brent, 2003), and then write questions or problems that assess one outcome at a time. The scores on this question are mapped to the assessment levels being used. The nationally normed Fundamentals of Engineering examination, the first step to becoming a professional engineer, provides excellent averaged direct assessment data for analyzing satisfaction of outcomes 3a, 3e, and, to a lesser extent, 3f.

Teaching and assessing the professional criteria remain hurdles for most engineering faculty. A number of direct assessments were initially developed, but the most powerful were also the most time consuming (Shuman et al., 2005). As a result many of the more detailed assessment procedures such as student portfolios, behavioral observations, and performance appraisals are seldom used on a large scale. *Rubrics* (detailed descriptions of what students at different levels of accomplishment can do) are commonly used by instructors for direct assessment of the professional criteria. Rubrics have the advantage that their use makes grading more detailed and fairer but does not significantly increase grading time. Use of a rubric forces the professor to look at the important components of the assignment. Sample rubrics are available in the literature (Rogers, 2010; Stevens and Levi, 2012; Walvoord and Johnson, 2010) and in this chapter's appendix.

Students often learn many of the skills necessary to satisfy the professional outcomes outside of class in internships, clubs, work, and research. Hirsch et al. (2005) studied students who were part of a summer research experience for bioengineers. The students made measureable improvements in satisfying ABET outcomes 3f and 3g without taking formal courses.

Recently, ABET examiners have been paying most attention to criterion 4, continuous improvement. Does the program regularly assess the student outcomes, evaluate the extent that targets are being met, and systematically use the evaluation results to improve the program? The key appears to be to have a plan that regularly, at least once per year, reports on the evaluation results to a committee or the department head, and then plans for improvement based on the data that are formulated and followed.

Table 4-5. Summary of ABET Criterion 5, Curriculum

Mathematics and Basic Science (biological, chemical, and physical, including some experimental) appropriate to discipline	1 year
Engineering sciences and design (curriculum must culminate in a major design experience—see Section 9.1) appropriate for the discipline	1.5 yrs
General education to complement the technical content	*
Base	4 years

* Amount not specified, but students need to meet the outcomes in Table 4-4.

Previously the curriculum was fairly constrained, but the current requirements (criterion 5) are quite general (Table 4-5). These are minimum requirements, and individual engineering disciplines may impose additional requirements. Previously, mathematical studies had to include differential and integral calculus and differential equations. This has been changed to be "appropriate to the discipline," leaving considerable latitude to the program. At the same time the program has to be ready to show that the mathematics and sciences are appropriate. In the past, programs often included computer science with the basic sciences, but this is no longer acceptable. The engineering sciences include mechanics, thermodynamics, electrical circuits, materials science, fluids, heat transfer fundamentals and so forth. Engineering design used to be a controversial area, but proving the students have had a major design experience is now simpler. The general education component includes both elective and required courses in humanities and social sciences. The laboratory experience should include design of experiments and interpretation of data (criterion 3b). The computer-based experience should be sufficient enough so that the student can demonstrate efficiency in application and use of digital computers (criterion 3k). Competency in written and oral communication (criterion 3g) is expected.

Criterion 6 considers only the faculty who are actually involved in the program. Those who are in the department but not involved with the program are not considered. Criteria 7 and 8 are typically not problems for institutions that do not have major budget difficulties. There can be a concern about leadership if no one is clearly in charge of the program. In addition to these general criteria, many programs have to satisfy program specific criteria. For example, computer engineering programs must include discrete mathematics.

4.7.3. The Impact of ABET-2000 on Engineering Education

The authors agree with Latuca et al. (2006) that the changes made in ABET-2000 have had a positive role in engineering education. The outcomes-based assessment used in ABET-2000 is more flexible than the former method. This has allowed one of the authors to accredit a multidisciplinary engineering program that would not have been accredited under the old rules (Wankat and Haghighi, 2009; see Section 4.8). Accreditation of novel programs is possible, but requires extra attention to assessment, evaluation of assessment, and continuous improvement.

Looking at individual outcome criteria and obtaining regular feedback from graduates and employers makes it much easier to spot deficiencies in the curriculum. Explicit requirements to teach and assess the professional criteria have improved graduates' skills (Latuca et al., 2006) and will help prepare graduates for jobs in the service sector (Wei, 2008). Writing and disseminating course objectives, which are required by ABET-2000, improves courses (Besterfield-Sacre et al., 2000).

We believe the main reason most engineering professors were initially against the ABET-2000 changes, and many are still against assessment and data-based decision making (Latuca et al., 2006), is that assessment partially focuses on the teaching effectiveness of faculty. Many professors resist evaluation of their teaching performance. Teaching methods appear to be more difficult to change than content.

We believe there are the following problems with the functioning of ABET:

1. ABET has not clarified the balance between minimum standards, continuous improvement, and the value of assessment (ABET, 2004). A program with highly accomplished students and graduates, but relatively weak documentation of assessment or of continuous improvement, will probably have more difficulty with accreditation than a program with much less accomplished students and graduates but with strong documentation of the assessment and continuous improvement systems. National norming (e.g., the Fundamentals of Engineering exam) would allow examiners to compare students' levels of learning.
2. Eleven criteria for learning outcomes are too many, and they should be streamlined. One option would be to have three, more general, criteria: engineering science, engineering design, and professional skills.
3. ABET's rules are not transparent. For example, ABET program evaluators will privately state that as long as a program does anything to teach and assess criteria 3h, 3i, and 3j, they accept it. If that is true, EAC should clearly state this in its written documentation.
4. The amount of documentation required is onerous. Page limits on each section would aid both programs and program evaluators.
5. ABET has realized for quite some time it needs to develop methods to ensure uniformity among program evaluators (ABET, 2004).
6. ABET needs to heed the methods used by Lattuca et al.'s (2006) major analysis of the effectiveness of ABET-2000. Their study relied on surveys and self-reports, which they carefully benchmarked as providing meaningful information. Ironically, engineering programs cannot use surveys and self-reports as their only assessments (Briedis, 2008).

4.8. CURRICULUM DEVELOPMENT CASE STUDY

The use of case studies in engineering education is discussed in Section 9.2.5. This case study can either be read through in the same way as the remainder of the text—as information—or it can be done as an interrupted case study by determining what you would do at each new subsection.

4.8.1. Background Information

In 1969 Purdue University developed an Interdisciplinary Engineering Studies (IDES) program that was purposely not ABET accredited so as to have maximum flexibility. In 2000 one of the authors (PCW) became the half-time program director. Since the students took their engineering courses from the other engineering programs, the director was the only faculty member paid by the program. The IDES program required 124 semester credits to graduate , which could be satisfied in eight semesters of full-time attendance taking a normal load of five or six courses for 15 to 16 credits each semester. The students took the same first year program as other engineering students (calculus I and II, chemistry I and II with lab, physics I with lab, English, speech, and introduction to engineering and computers). After completing the first year, students selected their engineering major, and, if they became IDES students, they also selected a concentration in IDES. In the sophomore year IDES majors took the same multi-variable calculus, differential equations, and physics II (electricity and magnetism) classes as other engineering students. The IDES students also took the same 18 credits of general education as other engineering students.

However, the IDES program differed by not having a required engineering core and requiring only 30 credits of engineering versus a minimum of 47 credits for an ABET accredited program. The difference of 17 credits was added to other electives to form the "area." Area electives (totaling about 30 credits) allowed students to take almost any course in the university to develop unique concentrations that were not possible in a standard engineering program. Examples included engineering management, acoustical engineering, and a student-designed option. Because of its flexibility, the IDES program was expected to serve as an incubator for development of new programs such as biomedical engineering.

Earlier policy had been to allow students to take courses that "were in the student's and Purdue's best interests." As a result rules were lax and some students found a relatively easy path to an engineering degree. The IDES program also had the largest percentage of students who entered the program by internal transfer—usually from another engineering program. IDES had thus become a haven for students who found other engineering programs either too difficult or distasteful. The requirements were tightened mainly by enforcing existing rules.

Many engineering professors felt that IDES students were well below average and were a burden to teach. In reality, because IDES also had a pre-medical engineering program and some students went well beyond the minimum requirements, the GPAs of students in IDES were bimodal. These professors also felt that they did not receive any recognition or benefits from teaching IDES students. Because IDES students were placed in existing classes when there was room available, the program was the least expensive per graduate in the university. The dean of engineering realized that the program served a purpose, but did not want the problems that would occur if the program grew. Thus, enrollment was limited to a total of 100 students, which kept complaints to a minimum.

Every year the director received letters from graduates who were not able to become Professional Engineers because of the lack of ABET accreditation. In the past, accreditation was not possible because ABET required a minimum of three professors in a program and a program that did not teach any of its engineering core would have been unacceptable. With the increased flexibility of ABET-2000 it might be possible to have an accredited program with the desired flexibility, but more faculty involvement would be required. Obtaining money and space for additional faculty was not fiscally or politically possible.

In 2003 a new dean of engineering constituted an ad hoc committee to consider changing the Department of Freshman Engineering (FrE) from a non-degree granting service department into a Department of Engineering Education (ENE). In addition to being in charge of the first year program, ENE would do research in engineering education and offer PhD and MS degrees. The Head of FrE was totally in favor of this change, and he had only accepted the appointment as the Head of FrE with the understanding that the department's role would be changed significantly. The IDES director, who was also interim associate dean of engineering for education, served on the committee. In an interesting intertwining of roles, the head of FrE and the director of IDES both reported to the associate dean.

After a few meetings of the ad hoc committee, the associate dean realized that the proposal for ENE would produce an incomplete department since there would be no undergraduate degree program. In his role as director of IDES the associate dean realized that the formation of ENE was an opportunity to obtain faculty dedicated to the IDES program, which would allow development of a program that met ABET accreditation requirements. However, IDES would have to relinquish its independence and become part of ENE. Independent control of budget and of space was the major advantage that would be lost.

Would you work to make IDES a part of ENE? Why or why not?

If you decided to work to make IDES a part of ENE, how would you go about doing this? What could go wrong?

4.8.2. Decision and Action Steps

After weeks of privately mulling over the possible ramifications of merging FrE and IDES, the IDES director decided that a merger would be in the best interests of Purdue and of the students. Not only would the merger give ENE an undergraduate program and allow IDES to pursue ABET accreditation, it would also make ENE stronger by providing extra space and budget.

What was the best way to accomplish a merger? Ordering the merger as associate dean or asking the dean to order the merger would undoubtedly cause faculty resistance. To avoid the development of unnecessary resistance, the associate dean requested that the dean change the charge to the committee to include the possibility of ENE developing an undergraduate program. Once the merger was explained to her, the dean agreed.

After the announcement of the change in charge to the committee, one unforeseen difficulty occurred. The Head of FrE demurred because he was afraid that he would be shunted aside. After he was reassured that the proposed merger was not a coup and he would remain as Head of ENE, he became an enthusiastic supporter.

In April 2004 FrE and IDES were merged to form ENE. The first order of business involved developing MS and PhD programs in engineering education. Once that task was well under way, early in 2005 the director of IDES, now a part of ENE, started planning for an ABET accredited program.

How does one plan a new ABET accredited engineering program?

Considering the background information, what constraints need to be included in the program design?

Which ABET program area would you seek to be accredited under? (Check out the ABET web site for the options.)

If the total credits to graduation are not changed, how many engineering credits would be required and what would the engineering core look like?

4.8.3. Design of the Curriculum

The new program had to fit within the context of engineering at Purdue, it had to satisfy ABET requirements, and it had to satisfy the major reason for seeking ABET accreditation, which was the thwarted desire of graduates to become professional engineers.

In the context of the engineering college the program would have to pass scrutiny of the Engineering Curriculum Committee (ECC) and of the Engineering Leadership Team, which consists of deans and heads. The program would have to follow the college rules: use the common first year program and follow the college's general education program. Since many engineering disciplines were already accredited at Purdue and since the program would be multidisciplinary, the decision was made to have the program be as flexible as possible subject to the constraints. We decided to seek ABET accreditation in the Engineering, Engineering Physics, and Engineering Science program area. None of the existing Purdue programs were accredited by this program area, and since there are no program criteria, the program would have maximum flexibility. Newberry and Farison (2003) classified the three types of general engineering programs accredited by ABET as philosophical, instrumental (planning to convert to disciplinary programs) and flexible. Purdue's program would fit with the ten flexible programs accredited in 2003. A timing constraint was that Purdue's next ABET visit would be in fall of 2007. To be accredited during this visit, the program needed a May 2007 graduate. The only way to have a graduate in two years was to have a transfer student be the first graduate.

Next, the constraints on the program were delineated. Total credits would be 124, the same as the existing IDES program. Since ABET accreditation was a major goal, the ABET requirements in Table 4-5 would have to be satisfied with at least 47 credits of engineering and 31 credits of mathematics and basic science. Purdue requirements of a common first year engineering program (8 credits math, 8 credits chemistry with lab, 4 credits physics with lab, 4 credits introduction to engineering including computer software, 4 credits of English and 3 credits of speech); common sophomore mathematics through differential equations (8 credits); and a common engineering college requirement of 18 additional credits of humanities and social science would be adhered to. Decisions were made to change the sophomore physics requirement to 3 credits of basic science and to make the engineering requirement 47 credits at the sophomore year and above (51 credits engineering total) to provide a cushion for experimentation.

The content of the engineering courses was constrained by the necessity of satisfying ABET criteria in Tables 4-3 and 4-4, and the desire to have students pass the Fundamentals of Engineering (FE) exam. The general part of the FE exam consists of questions in mathematics, probability and statistics, chemistry, computers, ethics and professionalism, engineering economics, statics, dynamics, strength of materials, material properties, fluids, electricity & magnetism, and thermodynamics. The math, chemistry and computers are covered in their first year and sophomore core courses. We decided to cover ethics and professionalism in a one-credit professional seminar that is part of the engineering core. The other courses in the engineering core are circuits, thermo, statics, dynamics, engineering economics, fluids, and a major design experience course. Total in the core is 19–22 credits depending on which statics-dynamics sequence is chosen. A 3-credit statistics selective is also required—most students take engineering statistics (a selective is a course chosen from a short list of alternatives).

The core is unique in that to maximize flexibility we follow the procedure used by the FE exam: instead of specifying courses we specify topics. For example, we accept any of the four beginning engineering thermo courses taught at Purdue. We initially had 5 credits of engineering selectives including 2 credits of hands-on lab and 3 credits of design. However, in the ECC the representative from Materials Engineering pushed very strongly to require a course in materials. After some negotiation, the ECC agreed on adding a 3 credit selective in either materials or strength of materials. Including this selective, students will have covered 93% of the topics on the FE exam. The remaining credits of engineering (usually 14) are used for depth in the students' concentration (e.g., acoustical engineering). Students also had 17 credits of free electives that were used to meet requirements of the students' concentrations. For example, students in engineering management take management courses and students in visual design engineering take computer graphics technology and art and design courses. Wankat and Haghighi (2009) discuss the program concentrations in detail.

A major challenge was to ensure that students satisfied ABET criteria 3 a–k (Table 4-4). Since all of the engineering courses are taught by ABET accredited programs, we could identify courses where technical criteria 3a, b, c, e, and k were taught and assessed. For example, criteria 3a and 3e are taught and assessed in statics regardless of which department teaches the course. All of the engineering programs also teach and assess the professional criteria, but they often do this assessment in courses that are seldom taken by students in the new program. The strategy for the professional outcomes 3d, 3f–3j, and 3l (an outcome on leadership added by the program) was to teach these outcomes and assess extensively in the professional seminar and in the major design experience courses. Since the students' concentrations can be quite different, we allowed students the option of taking either EPICS (Purdue's engineering service learning course, see Section 7.10) or a major design experience course offered by ENE faculty. Both of these options would do extensive assessment.

Flexible general engineering programs generally combine courses from the engineering disciplinary programs (Newberry and Farison, 2003). Because students took most of their core courses from the disciplinary engineering programs, the faculty of ENE originally taught only 4 credits: the 1-credit professional seminar and the 3-credit major design experience course. Because students in the new program take seats in courses that would otherwise be vacant, the program continues to be inexpensive for Purdue. The professional seminar was first offered in spring 2006 and every spring since then. Because ENE was in the process of hiring new professors, the ENE major design experience course could not be developed and offered until spring of 2008, which was after the ABET visit. The first graduate used EPICS to satisfy this requirement.

Since the program originally controlled less than 10% of the engineering credit taken by the students, what can the program do to show that the ABET criteria, particularly criteria 3 (Table 4-4), are satisfied?

What steps would you take to prepare for the ABET visit?

4.8.4. Visit Preparation

Every student was assessed in the professional seminar and the capstone design courses—sampling was not used in these courses. The assessment program included direct assessment of all criteria 3 outcomes, except for 3b (experiments), in the courses taught by ENE faculty. Indirect assessments by surveys and interviews of all criteria 3 outcomes were done in the professional seminar, and all graduating seniors were interviewed.

FE exam results were used for outcomes 3a and 3e. Although the FE exam is taken by volunteers, the majority of program graduates take the FE because it is highly recommended and the program reimburses students who pass the cost of the exam. Our data (collected after the first visit) shows no significant difference in the GPA of those who took the FE and who did not (passing rates do correlate with GPA). In addition, the program received sampled assessment data for most of the other core courses on what was supposed to be a three-year rotation, but ended up being somewhat erratic.

Starting a year early, the ABET self-study was prepared. Because of the novel features and complexity of the program, this document was considerably longer than most self-studies.

The final document was about 100 text pages and 200 pages of appendices. Although the document was started well in advance, it could not be finished until after assessment data from the spring semester was available in June.

Shortly before the first official graduate was scheduled to graduate in May 2007, the program director discovered that ABET does not allow accredited programs to have the same title as unaccredited programs. Thus, a new name had to be found quickly. All involved parties (the ENE faculty, the first graduate, the Industrial Advisory Council, Dean of Engineering, and the Registrar) agreed to the name Multidisciplinary Engineering (MDE) for the ABET accredited program. IDES was retained as a small unaccredited program.

Since Purdue has a number of professors who are ABET visitors, we asked many questions. However, there was a limit to the amount of time we thought we could ask volunteers to donate. We hired a consultant, a retired professor who had done a large number of ABET visits, to conduct a mock visit. This visit was extremely helpful and a bit humbling since we had overlooked a number of important items.

The MDE program's first official student to graduate was in May 2007 and the first ABET visit was scheduled for October of 2007. Notebooks including a syllabus, handouts, and examples of student work were assembled for the most commonly taken core courses. A major advantage of doing the MDE accreditation at the same time as the other engineering programs at Purdue was that engineering professors had to assemble notebooks for their program's accreditation. Thus, obtaining a copy for the MDE visit required very little extra work.

4.8.5. Final Results

The accreditation was successful and the program was accredited in summer 2008.

Between visits a number of improvements were made. Several graduates commented that a CAD course would have been very helpful. After discussions with the Industrial Advisory Council, a CAD course became a program requirement. As a second example, after the first ABET visit we noticed in exit interviews that students seldom mentioned any computer work during their sophomore and junior years. To increase the opportunity for students to satisfy criterion 3k and to increase the networking opportunities of MDE students, the MDE program started teaching our own engineering statistics course in the junior year. In addition, graduates were surveyed to check for satisfaction of objectives. Half of the graduates contacted responded. Most had already satisfied the program objectives or were well on their way to satisfying the objectives.

The second ABET visit was in October 2013. The program was fully accredited for a second time in summer 2014.

The take-home lesson here is that if you want to accredit a novel engineering program, you need to do extensive assessments of every student and then use the results to improve the program. This formula is simple, but faculty has to buy in to assessment to make it work. In addition, hiring a consultant to do a mock visit will be money well spent.

4.9. CHAPTER COMMENTS

Write detailed behavioral objectives once for one course. The experience will sharpen your teaching both in that course and in other courses, even if you do not formally write objectives for other courses. Bloom's taxonomy is extremely helpful in ensuring the proper distribution of class time, student effort, and quiz questions. Carefully classifying objectives and test questions as to the level on the taxonomy is also a very useful exercise to do for at least one class. Then in later classes the level will usually be obvious.

The ABET requirements may not be high on one's list of interesting reading. However, if new faculty are unaware of the ABET requirements, it is unlikely that their courses will meet the spirit of these criteria. This is particularly true of including professional criteria as some fraction of a course. In addition, to be informed participants in the current debate on accreditation requirements, faculty must understand the current requirements.

HOMEWORK

1. Pick a required undergraduate engineering course. Write six cognitive objectives for this course with one at each level of Bloom's taxonomy.
2. Write two objectives in the affective domain for the course selected in problem 1.
3. Pick an undergraduate laboratory course. Write two objectives in the psychomotor domain.
4. Objective 10 in Table 4-1 includes a cognitive and an affective domain objective. Classify each of these.
5. For the course selected in problem 1 decide whether a textbook should be used. Explain your answer.
6. The following statement can be debated. "ABET accreditation has strengthened engineering education in the United States."
   a. Take the affirmative side and discuss this statement.
   b. Take the negative side and discuss this statement.

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APPENDIX. SAMPLE RUBRICS FOR ABET PROFESSIONAL OUTCOMES

3d) An ability to function on multidisciplinary teams.

Attribute	Unacceptable	Marginal	Acceptable	Superior
Multidisciplinary team experience	No experience	2 or more experiences, but not extensive	Several experiences—at least one extensive	Multiple extensive experiences.
Identify effect of personal actions on team	Clueless	Can identify 1 positive and 1 negative action	Identify 2–3 positive and 2–3 negative actions	Identify > 3 positive and > 3 negative actions
Actual conduct	Consistently misses meetings, unprepared, does not do work	Often not professional. Late or miss meetings, not prepared, does not always do work	Usually professional: on time, prepared, does work said would do, fosters collaboration	Professional at all times. On time, prepared, does work, and fosters collaboration
Organization and workload distribution	No organization. Work distribution very uneven	Minimal organization. Some members limited contributions	Adequate organization with all members contributing significantly.	Excellent organization. All members participate fully
Team interdependence	Do not work together	Significant team problems in leadership, cooperation and interaction	Leadership, cooperation, and interaction are all evident and acceptable	Utilize strengths of each team member fully.
Team product	Poor. No team assessment or monitoring	Does not meet specs. Minimal assessment and monitoring	Meets specs. Self assess and monitor adequately	Surpasses specs. Self-assess and monitor during process.
Assessment by peers	Poor, very low ratings	Below average. Did some work, but not enough to earn team grade.	Good. Earned fair share of points and receive team grade.	Excellent. Did more than share of work and leadership.
Overall	Unacceptable	Marginal	Acceptable	Superior

3f) An understanding of professional and ethical responsibility.

Attribute	Unacceptable	Marginal	Acceptable	Superior
Can explain ethical and professional situation	Cannot determine any appropriate parts of code of ethics	75% of time can determine at least one appropriate part of code	Can determine one or more appropriate parts of code	Can determine multiple appropriate parts of code and prioritize their applicability
Can determine appropriate action	Unable to determine any appropriate action.	75% of time can determine at least one appropriate action.	Can determine one or more appropriate actions.	Can determine multiple appropriate actions and prioritize them.
Actual conduct	Unethical, cheating or plagiarism. Racist or bigoted behavior. Shady, marginally professional, often does not treat others with respect.	Honest, usually professional, and usually treats others with respect, but behavior indicates is following only letter of the rules.	Honest, usually professional and treats others with respect, and behavior indicates follows both letter and spirit of the rules.	Highly professional, honest, treats every one with respect. Believes in both spirit and letter of rules.
Overall	Unacceptable	Marginal	Acceptable	Superior

3g) An ability to communicate effectively by speaking and writing (written communication).

Attribute	Unacceptable	Marginal	Acceptable	Superior
Organization	Purpose unclear. No clear structure.	Purpose stated, but not helpful. Difficult to follow. No continuity.	Clear purpose and structure. Logical information format.	Very clear purpose and structure. Information logical and interesting
Content	No grasp of information.	Major gaps in content. Inappropriate content may be included	Appropriate content choice. Comfortable explaining content to some degree	Consistently appropriate subject knowledge, explanation, and elaboration
Abstract or Summary	None	Present, but marginally helpful	Too long with too much detail or too short without detail	Just right. Provides relevant details whilst concise.
Format & Aesthetics	Inconsistent. Changes in font etc.	Mostly consistent format.	Consistent format with appropriate headings and captions	Completely consistent and pleasing to the eye.
Data presentation and visuals	Sloppy figures and tables—hard to decipher.	Figures and tables legible, but not completely convincing.	Neat figures and tables provide needed information.	Exceptional figures and tables reinforce information in text.
Spelling and grammar	Numerous errors. Not proof read.	Several errors. Needs thorough proof reading.	A few minor errors.	Almost perfect. A joy to grade.
Style	Awkward. Impedes understanding.	Too dry or too florid, or alternatively both	Occasionally too dry or too florid.	Enjoyable to read and helps understanding
Citing and References	Although needed, none.	Inadequate inconsistent citing and referencing	Consistent. Minor problems.	Comprehensive. Logical and consistent.
Overall	Unacceptable	Marginal	Acceptable	Superior

3g) An ability to communicate effectively by speaking and writing (oral communication).

Attribute	Unacceptable	Marginal	Acceptable	Superior
Logical order	Disjointed. No organization	Parts are out of order.	Well organized—logic is obvious.	Enhances communication
Appropriate time use	Far too long or too short	Somewhat long or short	Appropriate length	
Objective	Not stated & not clear	Poorly stated	Clearly stated	
Background and significance	Not explained	Only one explained	Both explained	Both very clearly explained
Conclusions	None	Not clearly explained or not entirely logical	Explained and logical	Superior explanation and logical
Content	Inappropriate or incorrect	Mostly appropriate. Some errors	Appropriate and generally correct.	Appropriate and correct.
Visual aids	None, but should have some	Insufficient. Sloppy. Difficult to read	Easy to read. Relate well to content. Neat	Visuals reinforce content. Neat & clear.
Presentation (voice, poise, mannerisms, etc.)	Many distractions: no eye contact, mumbles. Monotone	Some distractions: little eye contact, mispronounces words	No distractions: Clear voice with proper variation. Has eye contact.	Clear voice—pleasant to listen to. Feels like person is speaking directly to you.
Response to questions	Nonresponsive Does not listen	Incomplete, poor listener	Clear and direct. Listens to questions	Repeats question. Complete yet concise.
Overall	Unacceptable	Marginal	Acceptable	Superior

3h) An understanding of the impact of engineering solutions in a societal/global/economic/environmental context.

Attribute	Unacceptable	Marginal	Acceptable	Superior
Explain impact of engineering on environment and society that is globalizing	No reasons and examples, or incorrect reasons and examples	Mainly ineffective evaluation and explanation of impact.	Mostly effective evaluation and explanation of impact with 2 or 3 reasons and 2 or 3 examples	Effective assessment and explanation of engineering impact, multiple reasons and examples.
Explain impact globalization will have on engineering	No reasons and examples, or incorrect reasons and examples	Mainly ineffective evaluation and explanation of impact.	Mostly effective evaluation and explanation of impact with 2 or 3 reasons and 2 or 3 examples	Effective assessment and explanation of engineering impact, multiple reasons and examples.
Broadens understanding of diverse and global cultures	No effort to broaden understanding	Participates in one activity to broaden understanding.	Participates in two or more activities, one is somewhat extensive.	Foreign lang. or participates in study abroad or extensive travel or multiple activities to broaden understanding.
Personal plan for success in a global society	No plan	Vague plan. No contingency plan	Plan with some ideas and directions	Well thought out plan including contingency plan
Overall	Unacceptable	Marginal	Acceptable	Superior

3i) An understanding of how one learns and recognition of the need for lifelong learning.

Attribute	Unacceptable	Marginal	Acceptable	Superior
Explain personal learning style*	No clue or extremely vague	Explains only one important personal learning style.	Explains 2 or 3 important aspects of personal learning style	Identifies/ explains all 4 items of personal style.
Explain methods to improve learning	Cannot identify or explain any methods	Can identify and explain 1 method to improve learning	Identify/ explains 2 or more methods to improve learning, with examples.	Identify/ explains multiple approaches and examples to improve learning.
Self-assessment and metacognition	No clue	Vague idea of how to self-assess and of learning progress	Reasonably accurate self-assessment. May monitor learning	Accurate self-assess, identifies areas to improve, and monitors own learning.
Life-long learning reasons	No reasons	Identifies one acceptable reason	Identifies 2–3 acceptable reasons.	Identifies multiple acceptable reasons
Personal plan for life-long learning	No plan	Vague plan. Some ideas for future. Might pursue more education in future	Has tentative plan and perhaps a contingency plan. Investigating professional development opportunities.	Extensive, specific plan and contingency plans for including professional development and additional education.
Personal life-long learning activities (for students, know of the activities)	No actions beyond going to class.	One or two activities such as attending convocations or belong to club(s).	Above and beyond just engineering. May do a minor. Attends some convocations or belong to club(s).	Above and beyond just engineering. Earning a minor. Routinely attends convocations and belongs to club(s).
Overall	Unacceptable	Marginal	Acceptable	Superior

* Personal learning style is based on Index of Learning Styles (Felder and Silverman, 1988).

3j) A knowledge of how contemporary issues affect engineering and how engineering can impact these issues.

Attribute	Unacceptable	Marginal	Acceptable	Superior
Demonstrates interest and knowledge of contemporary issues	Not interested and no demonstration of knowledge	Some interest. Demonstrates aware of major news items. No historical understanding.	Interested. Demonstrates reasonable breadth and depth. May have some historical understanding.	Demonstrates excellent breadth and depth of knowledge. Has some historical understanding.
How contemporary issues affect Engineering	Demonstrates no or very little understanding of how issues affect engineering.	Demonstrates basic understanding of how issues affect engineering for one contemporary issue.	Demonstrates basic understanding of how several issues affect engineering and in depth for 1 issue. Works to broaden understanding	Demonstrates excellent understanding of how many issues affect engineering and works to broaden understanding.
How Engineering affects contemporary issues	Demonstrates no or very little understanding of how engineering affects issues.	Demonstrates understanding of engineering implications for one contemporary issue.	Demonstrates understanding of engineering implications for several issues and in depth for 1 issue. Works to broaden understanding	Demonstrates excellent in depth understanding of engineering implications for many issues and works to broaden understanding.
Overall	Unacceptable	Marginal	Acceptable	Superior

CHAPTER 5

PROBLEM SOLVING AND CREATIVITY

An explicit discussion of problem-solving methods and problem-solving hints should be included in every engineering class. Heywood (2005) agrees, although he notes that the position can be debated. A problem-solving taxonomy was briefly discussed in Section 4.2.4. Most engineering schools are very good at teaching the lowest levels—routines and diagnosis—and most engineering students become very proficient at them. But students in general are not proficient at strategy, interpretation, and generation—three areas of the problem-solving taxonomy to be discussed throughout this chapter.

We will first briefly discuss some of the basic ideas about problem solving and compare the differences between novices and experts. Then present a strategy for problem solving which works well for well-understood problems, and discuss methods (heuristics) for getting unstuck. The teaching of problem solving will be covered with a number of hints that can be used in class. Finally, creativity will be discussed.

5.1. SUMMARY AND OBJECTIVES

After reading this chapter, you should be able to:

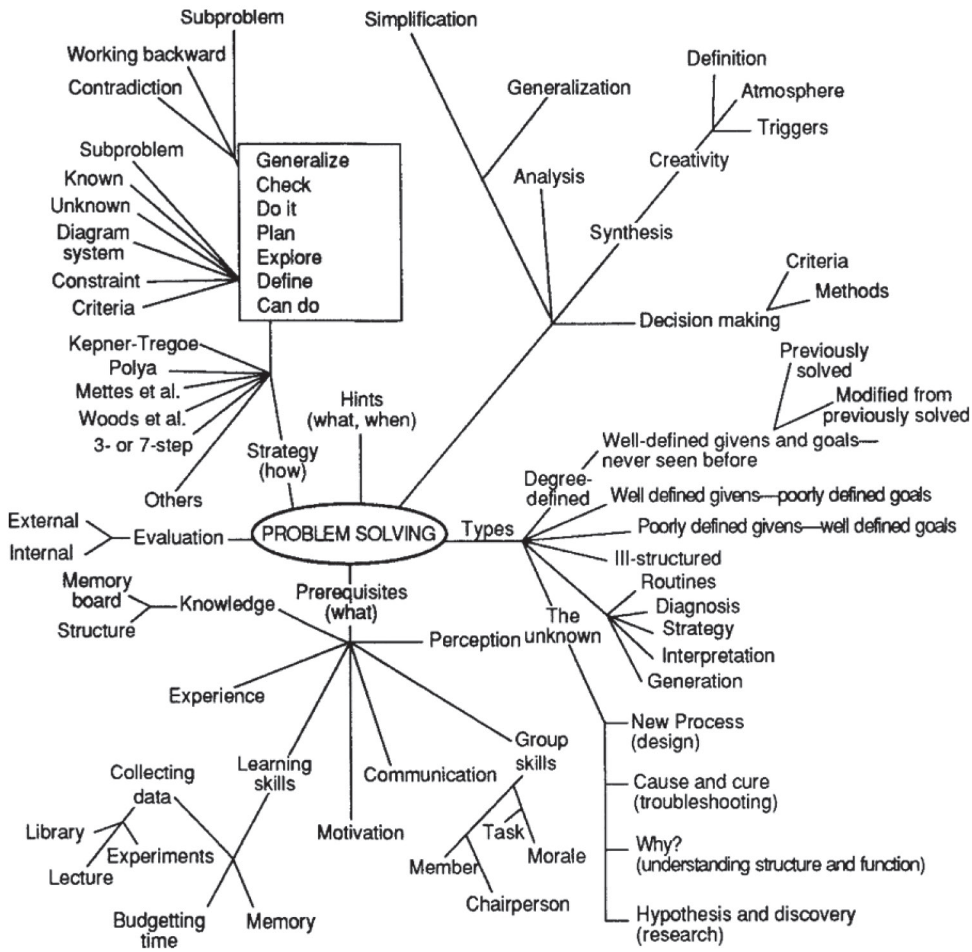
- Discuss and modify Figure 5-1 to fit your understanding of problem solving.
- Delineate the differences between novices and experts. Use these differences to outline how to teach novices to be better problem solvers.
- Discuss the steps in a problem-solving strategy (one different from the one discussed here can be used as a substitute) and use this strategy to help students solve problems.
- List and help students use some of the methods for getting unstuck.
- Develop a plan to incorporate both problem-solving and creativity exercises in an engineering course.
- Explain the three steps which can foster creativity and use some of the techniques.

5.2. PROBLEM SOLVING: AN OVERVIEW

The concept map shown in Figure 5-1 gives some idea of the interactions and complexities involved in problem solving (this figure is modified from Chorneyko et al., 1979). An entire book would be required to explain the information on this map fully. Readers who feel a need to understand parts of this map which are not explained in this chapter are referred to the extensive list of references at the end of the chapter.

Cognitive psychologists agree that there are generalizable problem-solving skills, but that problem solving is also very dependent upon the knowledge required to solve the problem [see Chapter 14 and Kurfiss (1988) for a review]. Of the prerequisites shown in Figure 5-1, knowledge and motivation are the most important.

Figure 5-1. Concept Map of Problem Solving (Chorneyko et al., 1979. Reprinted with permission from *Chemical Engineering Education*.)



Problem solving can be classified by the type of problem being solved. A classification scheme based on the degree of definition of the problem is useful since it ties in closely with a scheme based on the strategy required (Figure 5-1). Relatively structured strategies are most useful for well-defined problems (Mettes et al., 1981). Ill-structured and less well-defined problems need an approach which focuses on determining what the problem and goals are (Kepner and Tregoe, 1965; Fogler et al., 2013). Various multistep strategies are often appropriate for problems with intermediate degrees of definition (see Section 5.4). The classification based on the unknown is discussed by Chorneyko et al. (1979).

The various elements of problem solving in Figure 5-1 show how it interacts with other cognitive activities. Analysis and synthesis are part of Bloom's taxonomy, while generalization is a seldom-taught part of the problem-solving taxonomy and of the strategy used in Section 5.4. Many experts use simplification to get a rapid fix on the solution (see Section 5.3). Creativity is an extensively studied, but not really well understood, adjunct to problem solving. Creativity can be enhanced with proper coaching (see Section 5.7). Finally, decision making is often a part of problem solving which connects it to the Myers-Briggs analysis (see Chapter 13) and is a major part of the Kepner and Tregoe approach (Kepner and Tregoe, 1965; Fogler et al., 2013; Table 4-2).

5.3. NOVICE AND EXPERT PROBLEM SOLVERS

The vast majority of new engineering students in the US are novice problem solvers. How do the novices who start college differ from experts? A number of observations on how novice problem solvers differ from experts are listed in Table 5-1. The table is arranged in roughly the sequence in which one solves problems. It is useful to point out to students the differences between novices and experts. Explain that experts were initially novices. The students' engineering education is designed to help them along the path from novice to expert.

Table 5-1. Comparison of Novice and Expert Problem Solvers (Bransford et al., 2000; Fogler et al., 2013; Larkin et al., 1980; Lochhead and Whimbey, 1987; Mayer, 1992; Smith, 1987; Whimbey and Lochhead, 1982; Woods, 1980; Woods et al., 1979; Yokomoto and Ware, 1990)

Characteristic	Novices	Experts
Memory	Small pieces	"Chunks" or pattern
	Few items	~ 50,000 items
Attitude	Try once and then give up	Can-do if persist
	Anxious	Confident
Categorize	Superficial details	Fundamentals
Problem statement	Difficulty redescribing	Many techniques to redescribe
	Slow and inaccurate	Fast and accurate
	Jump to conclusion	Define tentative problem
		May redefine several times

Table 5-1. (Cont.)

Characteristics	Novices	Experts
Simple well-defined problems	Slow Work backward	~ 4 times faster Work forward known procedures
Strategy	Trial and error	Use a strategy
Information	Don't know what is relevant Stymied by incomplete data	Recognize relevant information Can draw inferences
Parts (hard problems)	Do NOT analyze into parts	Analyze parts & proceed in steps Look for patterns
First step done (hard problems)	Try to calculate (Do it step)	Define and sketch Explore
Sketching	Often not done	Considerable time spent Abstract principles Show motion
Limits	Do not calculate	Calculate for quick fix on solution
Equations	Memorize or look up detailed equations for each circumstance	Derive result from fundamentals except empirical correlations
Solution procedures	"Uncompiled" Decide how to solve after writing equation	"Compiled" procedures Equation and solution method are single procedure
Monitoring progress	Do not do	Keep track Check off versus strategy
If stuck	Guess Quit	Use Heuristics Persevere Brainstorm
Accuracy	Not concerned DO NOT Check	Very accurate Check and recheck
Evaluation of result	Do not do	Do from broad experience
Mistakes/ Failure to solve	Ignore it	Learn what should have done Develop new method
Actions	Sit and think Inactive Quiet	Use paper and pencil Very active Sketch, write questions, flow paths. Subvocalize (talk to selves)
Decisions	Process not understood No clear criterion	Understand decision process Clear criterion

Experts have about 50,000 "chunks" of specialized knowledge and patterns stored in their brains in a readily accessible fashion (Simon, 1979). The expert has the knowledge linked in some form and does not store disconnected facts. Exercises that require students to develop trees or networks can help them form appropriate linkages (Staiger, 1984). Accumulation of this linked knowledge requires about ten years or 10,000 hours. Since it is not feasible to accumulate this much information in four or five years, producing experts is not a realistic goal for engineering education. However, it is reasonable to mold proficient problem solvers to start them on the road to mastery.

People can typically store seven (plus or minus two) items in short-term (working memory). Since experts store chunked items, they appear to store a lot more than nine individual items. Students can also learn to chunk items by recognizing patterns. Experts chunk based on core concepts and guiding principles, and they store the rules for when the knowledge is useful (*conditionalize* the knowledge). Students tend to classify by surface similarities (e.g., systems with pulleys would be classified together) (Bransford et al., 2000). In addition to learning to pattern, students need to learn to conditionalize their knowledge. Professors can help by giving occasional review problems and not specifying the method to use.

The differences between novices and experts show some areas that engineering educators can work on to improve the problem-solving ability of students. In the category of prerequisites, students should be encouraged to learn the fundamentals and do deep processing. Knowledge should be structured so that patterns, instead of single facts, can be recalled. Because motivation and confidence are important, professors should encourage students and model persistence in solving problems. Students need to practice defining problems and drawing sketches. The differences between a student's sketch and that of an expert should be made clear, and the student should be required to redraw the sketch. Students need to practice paraphrasing a problem statement and looking at different ways to interpret the problem. A distinct strategy should be used (see the next section). Students should also practice breaking a problem into parts, and they need to be encouraged to do the explore step. A chug-and-plug mentality should be discouraged, and students should be encouraged to return to the fundamentals.

Once students know a strategy, encourage them to monitor their progress. Teach methods for getting unstuck (see Section 5.5). Then have them check their results and evaluate them versus internal and external criteria. After the problems have been graded, some mechanism for ensuring that students learn from their mistakes is required. Throughout the process encourage them to be accurate and active. Specifics of methods for teaching problem solving are discussed in more detail in Section 5.6.

5.4. PROBLEM-SOLVING STRATEGIES

When an expert verbalizes how he or she solves a problem, it is clear that a distinct strategy has been used for routine problems, problems where the expert knows what to do. Novices have a strategy also: it is a trial-and-error or guess-and-check strategy even for routine problems. The novice strategy is not very effective and does not help one become a better problem solver. For novel problems where the expert does not know what to do, even experts use trial-and-error, but they are more persistent and check results thoroughly.

5.4.1. Problem-Solving Strategy for Routine Problems

A distinct problem-solving strategy for routine problems should be demonstrated and then be required. Develop a handout with the steps of the strategy spelled out. Give the handout to students at the beginning of the semester and refer to the strategy often. The exact strategy used is not important, but the strategy should be used consistently and students should be required to use it. Woods (2000) collected over 150 published strategies and noted that most are quite similar. Most have between two and seven stages including an awareness of the problem stage, a definition stage and a verification stage. Earlier, Woods et al. (1979) had recommended that fewer than four stages is probably too short and not detailed enough to be useful.

Our strategy for routines is based on the work of Don Woods and his coworkers at McMaster University (Woods et al., 1979; Woods, 1987, 2000). Through the years their strategy has changed slightly. We have settled on a strategy with six operational steps and a pre-step that focuses on motivation:

0. I can.
1. Define.
2. Explore.
3. Plan.
4. Do it.
5. Check.
6. Generalize.

Step 0 is a **motivation** step. Since anxiety can be a major detriment to problem solving, it is useful to work on the student's self-confidence (Scarl, 2003; Richardson and Noble, 1983). Don't be subtle when first working on this step. Also, teach students a few simple relaxation exercises (Richardson and Noble, 1983; Section 2.7).

Step 1, the **define** step, is often given very little attention by novices. They need to list the knowns and the unknowns, draw a figure, and perhaps draw an abstract figure which shows the fundamental relationships (remember that most people prefer visual learning). The figures are critical since an incorrect figure almost guarantees an incorrect solution. The constraints and the criteria for a solution should be clearly identified.

Step 2, the **explore** step, was originally missing from the strategy but was added when its importance to expert problem solvers became clear (Woods et al., 1979). It can also be called "Think about it," or "Ponder." During this step the expert asks questions and explores all dimensions of the problem. Is it a routine problem? If so, the expert will solve the problem quickly in a forward direction. If it is not routine, what parts are present? Which of these parts are routine? What unavailable data are likely to be required? What basis is most likely to be convenient? What are the alternative solution methods and which is likely to be most convenient and accurate? Can we quickly set limits for the answer (e.g., concentrations and electrical resistances cannot be negative). What control envelope should be used? Does this problem really need to be solved, or is it a smoke screen for a more important problem? Many experts determine limiting solutions to see if a more detailed solution is really needed. Since novices are often unaware of this step, they need encouragement to add it to their repertoire.

In the **plan** step, formal logic is used to set up the steps of the problem. For long problems a flowchart of the steps may be useful. The appropriate equations can be written and solved without numbers. This is extremely difficult for students in Piaget's concrete operational stage (see Chapter 14). This step is easier for students who think globally and are intuitive, which means that students who prefer to think serially and sensing individuals (these terms are discussed in Chapters 13 and 15) need more practice.

Do it, step 4, involves actually putting in values and calculating an answer. This is the step novices want to do first. Even fairly skilled problem solvers often want to combine steps 3 and 4 and not develop a solution in symbolic form. The separation of the plan and do it stages makes for better problem solvers in the long run. Separating these stages makes it easier to check the results and to generalize them since putting in new values is easier. Sensing students (see Section 13.3.1) tend to be better at doing the actual calculations.

Checking the results should be an automatic part of the problem-solving strategy. Checking requires internal checks for errors in both mathematical manipulations and number crunching, and it involves evaluation with external criteria. A very useful ploy of expert problem solvers is to compare the answer to the limits determined in the explore step. The answer should also be compared to "common sense." This step requires evaluation, the highest level in Bloom's taxonomy, and many students will not be adept at it.

The last step, **generalize**, is almost never done by novices unless they are explicitly told to do it. What has been learned about the content? How could the problem be solved much more efficiently in the future? For example, was one term very small so that in the future it can be safely ignored? Were trends linear so that in the future very few points need to be calculated? If the problem was not solved correctly, what should have been done? Students need to be strongly encouraged to study feedback and then solve incorrect problems again.

In the *transition* between stages the problem solver should monitor progress (Woods, 2000). Have I made progress? What should I do next? If this approach is a dead end, are any parts useful?

Problem solvers who use this strategy consistently will use all levels of both the Bloom and the problem-solving taxonomies. However, students will rebel against using this or any other structured approach to solving problems. The problems they are asked to solve with a structured approach are not yet routine. If the problems are simple, a structured approach is not needed and if the problems are difficult many students doubt the approach is useful. Since many aspects of problem solving are automatic, making them conscious is uncomfortable and may inhibit the student for a period. An analogy is the self-taught golfer who starts taking lessons. Thinking about the swing so that it can be improved makes it difficult to swing effortlessly. However, in the long run the person with training will become a better golfer or problem solver. (Note that an expert golfer is an expert problem solver in this narrow domain.) Student resistance can be overcome by consistently using the structured approach in examples and consistently requiring that students use the structured approach,

Many other problem-solving strategies can be used for routine problems. Polya (1971) originated a four-step approach which is a predecessor of the approach shown here. Since Woods (1977; 2000) has published extensive reviews of problem-solving strategies, these strategies will not be reviewed in detail here. Scarl (2003) also describes a procedure very similar to that presented here, and in addition he is very directive of what students should do. Mettes et al. (1981) describe a systematic flow sheet approach for solving thermodynamics problems that is quite different from the method illustrated here. Smith (1987) discusses expert system models for problem solving. Kepner and Tregoe (1965) developed procedures that are most applicable to determining what the problem is (troubleshooting) and for decision making that can be taught to engineering students (Fogler et al., 2013). Guided design is a method for guiding groups of students through a structured problem-solving procedure (Wales and Stager, 1977; Wales et al., 1986) (see Section 9.2.5).

5.4.2. Problem-Solving Strategy for Novel Problems

Problems engineers face at work "are ill-structured and complex because they have conflicting goals, multiple solution methods, non-engineering success standards, non-engineering constraints, unanticipated problems, distributed knowledge, collaborative activity systems, the importance of experience, and multiple forms of problem representation" (Jonassen et al., 2006). When they are confronted with a novel problem, one where the problem solver does not know what to do, even experts resort to a strategy that includes a significant amount of trial-and-error. Bodner (1991) studied the problem solving of chemists when confronted with novel problems. He developed an *anarchistic* model of problem solving. According to Bodner's model, here is a typical transcript of an expert solving a novel problem.

Read The Problem (RTP)
RTP again
Write down what appears to be relevant information
Do whatever may help to understand: Sketch, make a list, write equations, and so forth
Try something such as solving what may be a part of the problem
See if you have made any progress
Draw another sketch, make another list, and write more equations
Try something else
Check if you have made any progress
RTP
Draw another sketch, etc.
Try something else
See where this gets you
Test intermediate results
RTP
Get frustrated
Write down an answer—any answer
Check the answer
If answer is not correct, take a break
Start over and RTP

What makes this the efforts of an expert instead of a novice? The expert writes things down, draws sketches, uses a strategy for subproblems that are familiar, monitors progress and checks answers. As a result, the expert recognizes useful steps quicker than do novices. In addition, the expert expects the problem to eventually make sense, even if it takes years. What is the biggest difference between novices and experts? *The expert never gives up*!

5.5. GETTING STARTED OR GETTING UNSTUCK

A problem-solving strategy is not much help if you just cannot get started on a problem or are completely stuck. What do you do then? Novice problem solvers tend to give up or make wild guesses, whereas experts persist, recycle back through the Define step, and use heuristics.

When students are stuck, your first step is to encourage them. Remember those high school football slogans, “When the going gets tough, the tough get going!” and “Winners never quit, and quitters never win!” and so forth? A short pep talk is not out of order, particularly for students who have the prerequisites to be successful. Nothing makes a student more confident in her or his ability to solve problems than successfully solving difficult problems.

Second, encourage the student to recycle or loop in the steps of whatever problem-solving strategy the class is using. Ask, “Have you reread the problem statement to be sure you are solving the right problem?” “Have you rechecked your figures for accuracy?” “Have you thought about whether your plan of attack still seems reasonable?” Novices want to apply a strategy once through, while experts apply a strategy in a series of loops. One advantage of having an explicit strategy is that you can easily refer the student to a particular stage of the process, and both of you will have a common language.

If recycling through the strategy does not work, suggest that the student identify his or her difficulty with the problem. Where is the student stuck? What is the obstacle? Where does the student want to be? Are there alternatives that can be used? Sometimes this process will lead the student to a productive path.

If still stuck, it is time to use heuristics. *Heuristics* or *rules of thumb* are methods which might, but are not guaranteed to, work. A large number of heuristic methods have been suggested (Adams, 2001; Koen, 2003; Polya, 1971; Rubenstein and Firstenberg, 1987; Scarl, 2003; Smith, 1987; Starfield et al., 1990; Wankat, 1982; Woods et al., 1979). A very large number of heuristics can be listed; however, it probably does not matter which ones students are taught as long as they use them. For any given obstacle many different heuristics will work, since the heuristic gets the problem solver thinking productively on a new path. (Students need to realize this also—and it can be called another heuristic.)

The **second** and **third** suggestions in this section (recycle and find the obstacle) can be considered either heuristics or parts of the problem-solving strategy. We will list a variety of other heuristics. Select from these the ones that you will teach to the students, remembering that they will need to practice using the heuristics and will need feedback. With novices, it is preferable to keep the list short so that they can remember and use the heuristics.

1. *Simplify the problem and solve limiting cases*. This procedure is often used by experts. A closely related heuristic is “solve special cases.”
2. *Check to see that the problem is not under- or over specified.* Problems that are under- or over-specified need interpretation before they can be solved.
3. *Relate the problem to a similar problem which you know how to solve*. Solutions to similar problems can give a useful outline of how to solve the current problem. A closely related technique uses analogies to give hints about the problem solution.
4. *Generalize the problem*. Sometimes the problem is easier to understand and solve in a very general form.
5. *Try substituting in numbers*. Sometimes the problem will be clearer with numbers inserted.

6. *Try solving for ratios*. Often a problem can be solved for ratios, but not for individual numbers.
7. *Get the facts and be sure there actually is a problem*. Another way to say this is, "If it ain't broke, don't fix it." This heuristic can be taught and reinforced in the laboratory.
8. *Change the representation of the problem*. If the first representation of the problem is too difficult, change it.
9. *Ask questions about the problem*. Specifications are often set arbitrarily but may make the problem extremely difficult to solve. Question them. Does the purity have to be so high? Do the tolerances have to be so tight?
10. *Concentrate on the parts of the problem that can be solved*. Very often parts that seem unsolvable become solvable when other parts of the problem have been solved. This is partly a confidence factor.
11. *In groups, be a good listener and maintain group harmony*. Groups can be synergistic in solving problems, but only if people listen and there is some group harmony.
12. *Use a plus-minus-interesting (PMI) approach when presented with possible solutions* (de Bono, 1985; Gleeson, 1980). The plus helps the morale of the person suggesting the solution. Minuses are why the solution is not yet complete. Interesting are the ideas that can be adapted.
13. *Alternate a broad look at the entire problem with in-depth looks at small parts of the problem* (Rubenstein and Firstenberg, 1987).
14. *Alternate working forward and backward*. Although experts work forward on simple problems, they alternate working forward and backward on difficult problems.
15. *Take a break*. This is not quitting but is a break allowing you to do something else before returning to the problem with a fresh view.
16. *Ask what the hidden assumptions are or what you have forgotten to use*. Novice problem solvers often limit their solutions by assuming constraints which are not part of the problem.
17. *Apply a control strategy*. Experts keep track of where they are in solving a problem with a metacognitive control strategy. A metacognitive control strategy means consciously thinking about the processes we are using while problem solving. Schoenfield (1985) suggests that you ask yourself three questions: What are you doing? (Be exact.) Why are you doing it? How will it help you solve the problem?
18. *Refocus on the fundamentals*. Sometimes asking what is fundamental will break the log jam.
19. *Guess the solution and then check the answer*. Yes, guessing is a novice approach. However, sometimes when we are stuck, we have strong hunches. If we guess the answer, it may be easy to prove whether it is correct or incorrect. The differences between novice and expert behavior are that the expert makes her or his guess after working on the problem for a period and always checks the guess.
20. *Ask for a little help*. Even experts ask for help. The key is to get only a little help and not to let the helper solve the problem for you.

To close this section it may be useful to consider the six categories of blocks which Adams (2001) has identified. *Perceptual blocks* are difficulties in seeing various aspects or ramifications of the problem. *Cultural blocks* lead to inadvertent assumptions about the solution method or the solution path. In engineering there is a cultural bias toward convergent (logical) thinking and away from divergent (lateral or creative) thinking. *Environmental blocks* are due to the problem solver's surroundings, including people. For students this means the professor and other students. A lack of acceptance of novel ideas can be a major environmental block. *Emotional blocks* such as anxiety or fear of failure can make problem solvers much less effective. *Intellectual blocks* can include a lack of knowledge or trying to use inappropriate knowledge. The use of unannounced review questions on homework can help overcome this block. *Expressive blocks* involve the use of inappropriate problem-solving languages or inappropriate paths. For example, trying to solve a problem without an appropriately drawn figure can be an expressive block. An additional heuristic is: Determine the blocks that are preventing you from solving the problem.

5.6. TEACHING PROBLEM SOLVING

Many excellent papers and books have been written on how to improve the problem-solving abilities of students. Readers interested in more ideas and applications are referred to the literature (Fogler et al., 2013; Kurfiss, 1988; Lochhead and Whimbey, 1987; Lumsdaine and Lumsdaine, 1994; Plants, 1986; Rubenstein and Firstenberg, 1994; Scarl, 2003; Starfield et al., 1990; Stice, 1987; Wales and Stager, 1977; Wales et al., 1986; Whimbey and Lochhead, 1999; Woods, 1987; Woods et al., 1997).

Lumsdaine and Lumsdaine (1994) and Rubenstein and Firstenberg (1994) recommend a separate course in problem solving. However, specific knowledge in the problem domain is essential for solving problems. We suggest embedding problem solving into existing engineering courses. Then, the problem solving and specific knowledge can reinforce each other. It is helpful if the knowledge is organized by students in a hierarchical structure, since this is what most expert problem solvers do. Some information at the knowledge and comprehension levels of Bloom's taxonomy is essential, and professors should not hesitate to require memorization of certain crucial numbers. Most problems in lower-level engineering classes require facility with algebraic manipulations. Thus, it is essential that students master algebra. Obviously, other mathematical skills are important, but algebra appears to be the lowest common denominator.

Problem solving should be taught throughout the student's college career. The most extensive application of this is probably the McMaster University Problem Solving Program (Woods et al., 1997). Few schools have been willing to make this extensive a commitment to problem solving. However, problem solving throughout the curriculum can often be done in the form of little hints or suggestions of a heuristic to try while students are struggling with problems. Ideally, the same strategy would be used in all science and engineering classes and in textbooks. However, since most strategies are similar, students will not be hopelessly confused if the strategy changes. Illustrate the strategy when solving problems in class and in handouts. This includes solutions to homework and test problems. Many students will learn to use a strategy on their own, but students most in need of help in problem solving will not use a strategy unless required to. Encourage and perhaps even require students to use the strategy.

Although no student can become an accomplished problem solver merely by watching a professor solve examples, example problems are an important learning device, particularly for sensing students. Unfortunately, most professors inadvertently foster the idea that problem solving is a neat process and thereby do damage to the student's confidence. Using a routine to determine an answer is a neat process once the problem has been interpreted, a strategy chosen, the problem diagnosed, and the routine selected. These other steps are messy but represent the real heart of problem solving. Suppose that solving a problem takes fifteen minutes and results in two dead ends and a page of scrap paper. A professor's typical approach is to clean this up and show it to the students in five minutes with no mistakes and no dead ends. What the students see is a process that they cannot duplicate. Then when they are unable to solve problems in this way, they begin to doubt their abilities. Occasionally show a messy solution. Solve a problem in front of the class that you have not seen before and verbalize as you solve it. Have students select a problem from the textbook for you to solve. This is scary since you may fail. However, it does demonstrate the process that one goes through when solving novel problems, including step 0, the motivation or confidence-bolstering step.

Students need to solve problems to learn how to solve problems. At most, rote learning and drill will teach how to do routines, which is necessary but not sufficient to becoming a good problem solver. Students need to solve more challenging problems requiring all levels of the problem-solving taxonomy. All you have to do with the better students is to challenge them with good problems and provide feedback. But, this classical procedure does not work with the poorer students. Yet, these poorer students have the potential to become excellent engineers. How can you teach problem solving to make it accessible to them?

Particularly for beginning students, requiring a neat regular structure is useful. Tell students to lay out the problem solution in the same format for all homework problems. Require separate labeling of steps in the problem-solving strategy. Make students work down one side of the paper in regular columns. Encourage students to doodle, try out ideas, and play with the problem on a separate piece of scrap paper. Encourage them to write things down since this external memory is often more effective than trying to store ideas internally and paper is much cheaper than time. Require a sketch even for students who can solve the problem without it. Students should briefly define all symbols even if they are the same ones as in the book. Before plugging in numbers, they should obtain an algebraic solution in symbolic form. Until an individual student has proven that he or she can skip algebraic steps, all algebraic steps should be shown. A separate equation line with all numbers and units substituted into the equation should be shown before the student calculates the answer. Obviously, students will resist this degree of regimentation. They will truthfully say that they are now slower and poorer problem solvers. In the long run a structured procedure will produce better, neater, faster, more accurate problem solvers, and in the short run troubleshooting their solutions will be much easier. Since there is no reason why creative solutions cannot be neat and understandable, this procedure will not deaden creativity so long as solutions are graded with an open mind when they are different.

Give a combination of application, analysis, synthesis, and evaluation problems. Be sure that the homework problems range in difficulty from less difficult to more difficult than the test problems, or students will think you are unfair. Be sure that some problems require the simultaneous solution of equations, or students will believe that all problems can be solved sequentially. Encourage students to use spreadsheets to solve homework problems. Some problems should be open-ended, and synthesis should be required. Often students who excel in these problems are not the same students who excel in doing routines. Require students to evaluate solutions.

Separately cover all steps of the problem-solving strategy. For example, for one problem the students might do only **define**, **explore**, and **plan** steps. Give multipart problems where students first have to define and draw a sketch; then after the entire class has received feedback and has that step correct, they would do the next step, and so on. This *deliberate practice* is slow, but very effective. Require students to completely check their solutions by solving the problem with a completely different method. Then note that the answer is wrong if incorrect values for physical parameters are used. The **check** step can also be reinforced by making up homework assignments that include solutions to some of the problems, but some of the solutions are imperfect (Armstrong, 1995). The students are required to determine when their solutions differ from the presented solution and then determine which solution is correct. Since accuracy is important for practicing engineers, students must practice this level of accuracy. For problems where accuracy is being stressed, return the problem to the student for a corrected solution if there are any errors.

Try to cover all aspects of the problem-solving taxonomy. Give a few problems that are carefully worded to be ambiguous so students can practice interpretation. Require students to find or estimate some of the physical constants they need (and be prepared for a variety of solutions). Give them the assignment of making up a problem so that they have practice in defining problems. Give them real cases where a clearly defined problem is not laid out in front of them. These can include troubleshooting, debugging, or debottlenecking problems.

Students can be made more aware of their problem-solving procedures by verbalizing what they are doing while solving problems. This can be done conveniently in class with the Whimbey-Lochhead pair method (Lochhead and Whimbey, 1987; Whimbey and Lochhead, 1999). The class is divided into pairs, and one member of each pair is designated the problem solver whose job is to solve the problem and to say out loud *everything* he or she is thinking while solving the problem. The other person is the recorder-encourager who takes notes on what the person is doing and encourages the problem solver to keep verbalizing. As the encourager he or she can say things such as, "What are you thinking now," or "Tell me what you're thinking." As the recorder he or she needs to try to understand every step, diversion, and error made by the problem solver. When the reasons for a step are unclear, the recorder asks what the problem solver is doing and why. The recorder can point out algebraic or numerical errors but should not be specific as to where the error is. The two cardinal rules for the recorder are to avoid solving the problem and to not lead the solver toward a solution.

After explaining the roles to students, give the problem solver a short written problem statement. Then, as students start to read this to themselves, remind them they have to read out loud. Encourage them to verbalize their anxiety as they read a new problem and encourage them to verbalize self-encouragement. Encourage the problem solver to use a pencil and paper while solving the problem. During the remainder of the solution of the problem, visit various pairs and reinforce the role of each student.

Once the problem has been completed, either correctly or incorrectly, the recorder and the problem solver should discuss what the problem solver did while solving the problem. Remind students that learning how one solves problems is the purpose of the exercise, not correctly solving the problem. Students can then switch roles and solve a new problem.

To be effective, this procedure needs to be used several times during the semester. Note that it can be used in quite large classes. It keeps students active and simultaneously teaches both content (the problems chosen) and problem solving. This type of activity is a nice break from excessive lecturing. Professors should also verbalize while they solve example problems.

Problem solving can also be taught with discovery methods of instruction (Canelos, 1988). These approaches include simulation, case study, guided design, and discussion. In all these methods students should work on real, or at least realistic, engineering problems. They should help define the problem and then work at developing a solution. Then push the students to evaluate their solution and look for a better one. When the process is completed, help the students describe the problem-solving process so that they discover the method. These methods are suitable for either individual or group work. Further details of these methods are given in Chapters 7 through 9.

Student work in groups is particularly conducive to learning problem solving. Being in a group of one's peers can help reduce a student's anxiety if it is clear that no one has all the solutions. Extroverts and field-sensitive individuals will benefit from the group support. The verbalization that occurs in a group provides feedback. Groups help clarify difficult-to-interpret problems since each group member will look at the problem differently. Brainstorming during the explore step is easily done in groups. From the professor's viewpoint it is more efficient to work with groups of three to five students rather than individual students since the number of questions is reduced. Finally, new engineers are expected to work in teams in industry. Providing practice in teamwork while they are students will help their transition to industry.

Do not give students what they want—the solution. You want them to find a solution on their own and to improve their problem-solving skills. Encourage them to verbalize and refuse to let them quit prematurely. You can check to see if the students' knowledge base is correct and can help them see the hierarchical structure of the knowledge. You can also focus their activities on problem-solving methods. For example, if they are stuck, you can ask, "What heuristics have you tried?" and "What other heuristics can you try?" If students are stuck on a clearly incorrect approach, show them why they are incorrect but without showing them a correct approach. A brief outline or script of how you want to proceed will help you to remember to cover all important points.

5.7. CREATIVITY

Creativity can be a part of problem solving, but many successful solutions do not illustrate creativity. Creativity requires divergent thinking that usually appears at the **define** or **explore** step in problem solving if it is present. de Bono (2008) says creativity is about possibilities. Including possibilities during the explore step can lead to creative solutions. Note that creativity is only part of the entire problem-solving step. The creative idea must be proven to be a valid solution by a logical analysis during the **plan**, **do it**, and **check** steps. The generalize step can be used to further develop the creative idea and to look for other applications. The importance of creativity in engineering is summarized by Florman (1987, p. 75): "Engineering is an art as well as a science, and good engineering depends upon leaps of imagination as well as painstaking care." More recently, the National Academy of Engineering (2004, p. 55) wrote "Creativity (invention, innovation, thinking outside the box, art) is an indispensable quality for engineering, and . . . creativity will grow in importance."

Everyone is born with creative abilities. According to Hueter (1990) these abilities increase in elementary school up to an age of about eight and then steadily decrease with further schooling. At about eight years old children become very aware of the opinions of other people. It becomes important for them to fit in and to use objects for "what they are supposed to be used for." The result is a decline of creativity that continues through college. If Hueter is correct, then engineers are in a paradoxical situation. The very education which makes an engineer more capable of solving difficult problems decreases the likelihood that he or she will invent a creative solution. However, creativity can be enhanced with a positive attitude, suitable exercises (Christensen, 1988; de Bono, 2008), and creativity training (Zappe et al., 2012). Both creativity courses (Allan, 1994) and training the faculty to include creativity in their engineering design courses (Zappe et al., 2012) increase the creativity of students.

Nurture the creative abilities everyone possesses and help stem any decline in creativity. Here's what you can do to encourage the latent creativity of every student:

1. Tell students to be creative.
2. Teach students some creativity methods.
3. Accept the results of creative exercises.

5.7.1. Tell Students to be Creative

People are more creative when they are told to be creative. More creative solutions are generated when people are told to generate many possible solutions. There appears to be a bias, particularly among college students, toward producing a single solution unless explicitly told to produce multiple solutions. Thus, the first step is surprisingly simple. Ask for many solutions:

"Develop some creative solutions for this problem."

"Give some different ways to interpret this problem statement."

"List twenty (or fifty) possible solutions to this problem."

Once a large number of possibilities have been generated, you can ask students to further develop two or three of these ideas. For example, in a design class the assignment could be to develop a folding cane. Students are asked to generate twenty different possibilities and then to do detailed designs for two of these ideas. You need to accept ideas positively even if they probably would not work. The second part of this assignment asks students to do the necessary work and logical analysis to make the creative idea work. A second example that is applicable to any class is to require students to write homework or test questions with answers (Felder, 1987). This is a useful problem-solving exercise for students at all levels, and it becomes a useful creativity exercise also if students are told that grading will depend upon the novelty of their questions. Since this exercise will be quite time-consuming, group work is suggested for undergraduates. A third exercise is to ask students to identify as many uses for a common object (e.g., a brick or a pencil) as possible (Christensen, 1988).

5.7.2. Creativity Techniques

Cross-fertilization of knowledge is required to be creative (Prausnitz, 1985). Students should not overspecialize and take a variety of courses in many areas including advanced-level courses in different disciplines. The edges between disciplines are often the most productive areas for creative ideas.

Engineering instructors can choose from a variety of creativity techniques. Brainstorming was invented by Osborn (1991) and the term is now part of common usage. The technique is easy to use in class:

1. Present the problem.
2. Develop a lot of ideas.
3. Build on the ideas of others.
4. Make no criticism during the development phase.
5. Evaluate the ideas afterward.
6. Further develop promising ideas or combinations of ideas.

Encourage students to generate more ideas and ensure that there is no criticism during this stage. In a design class different design teams can be assigned to further develop these ideas.

These principles can be applied to other creative exercises. For example, individuals can brainstorm by themselves. Groups can brainstorm in a conference call, by e-mail, or through social media. In all cases the idea generation and evaluation stages must be separated; otherwise, the evaluation will inhibit idea generation. Most introductions to brainstorming skip the evaluation stage when the "grind of organization and evaluation" occurs (Allan, 1994, p. 273). In a separate creativity course several class periods can be set aside to do the complete brainstorming cycle.

Lateral thinking, (de Bono, 1973, 1985, 2008) involves restructuring patterns, changing viewpoints, jumping around, deliberately trying to change things, changing the problem statement, and avoiding logical (vertical thinking) analysis. Lateral thinking, unlike logical analysis, does not have to be sequential, does not have to be correct at each stage, does not have to use relevant information, and is not restricted to the problem as posed. Lateral thinking is used only to generate ideas, and proposed solutions are completely checked by logical analysis in the later stages. Essentially, lateral thinking is more an attitude than a method. A few examples will help illustrate. Answers to these examples are presented after section 5.8.

Example A. The same amount of money can be collected in tolls at less cost and with less disruption of traffic by closing half the toll booths. Explain how this could be done.

Example B. A process called **reversal** can be illustrated with the following problem: The occupants of a new office building complained that the elevators were too slow and that the wait for elevators was too long. Try rephrasing the problem statement several different ways and then solve the different problems. The point of the example is *not* to find the exact solution deBono discusses, but to practice reframing problems.

Example C. Dieting is a problem for many people. The straightforward solution is to tell people to eat less. A great deal of money has been spent on variations of this straightforward solution. What is the reversal solution? Go ahead and think up some ideas—none are wrong.

Many of the heuristics, challenges to students and exercises discussed in the remainder of this section can be considered part of lateral thinking.

Writing can be very useful for getting students to think about thinking and creativity (Allan, 1994; Raviv, 2012). Writing in a journal or diary is a useful method for encouraging creative thinking. Writing works best if done as free writing or as fast exploratory writing where the student just writes without worrying about grammar or spelling. For example, he or she might write a page about uses for a screwdriver. You can also have students develop an idea map, which can be considered a less sophisticated version of a concept map (Figure 5-1).

Challenging students with creative games, questions, and exercises is a good way to increase their creativity (de Bono, 2008; Felder, 1988; Raviv, 2012). Although these do not have to be tied to engineering content, some students will think activities not related to the course topic are a waste of time. For example, have them brainstorm 100 possible uses for a brick. Ask them the meaning of word games such as:

Example D. What is "12safety34"?

Example E. What is "milonelion"?

Students who speak English as a second language may have difficulty with word games. There are also many mathematical exercises that require creativity to solve rapidly.

Example F. In a single elimination tennis tournament with 360 players, how many matches need to be held to determine the winner?

Gardner (1978) is a good source of both problems and references for additional problems. Open-ended creative questions do not have to have answers.

Example G. Why do bridges freeze before the road surface? How could this be prevented?

Example H. What is a good economical use for snow?

Heuristics were discussed extensively in Section 5.5, and many of them are useful for the generation of creative ideas. A few of many possible creativity heuristics are listed below.

1. *Have many ideas*. The more ideas, the more likely one will be good (Christensen, 1988).
2. *Reverse the problem*.
3. *Build on a random stimulus* (de Bono, 1971). For example, pick a word at random from the dictionary and see if it leads to any possible solutions.
4. *Think of something funny about the problem* (Allan, 1994).
5. *Think of analogous solutions in nature to similar problems*. This is a key part of the synectics approach to creativity (Gordon, 1961).
6. *Develop word lists of stimulus words, properties, or key concepts* (Staiger, 1984).
7. *Use creativity methods such as borrowing brilliance, fishbone diagramming, and mind mapping* (Walesh, 2012).
8. *Show an invention or drawing of an invention and ask students what it is* (Raviv, 2012).
9. *Use checklists or keywords to trigger different ways of looking at a problem*. For example, the word creativity can be used (Sadowski, 1987):

C - combine
R - reverse
E - expand
A - alter
T - tinier
I - instead of
V - viewpoint change
I - in another sequence
T - to other uses
Y - yes! yes! (affirm new ideas)

Most engineers tend to be heavily left-brain oriented (Walesh, 2012). Their creativity can be enhanced by having them learn how to shut off the left brain and use the right brain. Following the pioneering work of Roger W. Sperry, it is now clear that the left hemisphere of the brain is mainly involved in verbal analytical thinking. The right hemisphere mainly processes visual and perceptual thinking, and its mode of processing involves intuition and leaps of insight.

People can learn to consciously shut off the left brain and use the subdominant right brain by giving the whole brain a job which the left brain will refuse to do (Edwards, 2012). You will do a much better job teaching students how to shut off their left brains if you become reasonably adept at this creativity approach. Practice the shift from left to right brain by looking at perceptual illusion drawings and consciously forcing yourself to see one part of the illusion and then another. Examples of this type of drawing are the vase that becomes two faces and the many drawings by M. C. Escher. A second exercise is to look at photographs of familiar faces, but with the photographs upside down. This exercise requires a shift in pattern recognition. A third exercise is to draw using the right side of the brain without using words to name parts. Edwards' (2012) book has detailed exercises for learning how to do this. While doing these exercises you may want to quietly reassure the left brain that you will return to it shortly. To be able to shift at will to right-brain thinking, you must monitor brain activity so that you know when the shift has occurred. (A personal note: We find that our most creative ideas often come when we are tired. Apparently being tired relaxes the control of the left brain and the right brain has the chance to generate ideas. This can happen only if the problem has been thoroughly considered previously.)

Remember that the purpose of teaching engineering students how to shift to the right brain is to provide them with an alternative way of looking at things since this may produce creative ideas for solutions. Once the ideas are generated, the left brain takes over to evaluate the quality of the ideas.

To incorporate creativity successfully into a class, Flowers (1987) suggests one needs willing students, an enthusiastic instructor, "good" problems, and appropriate feedback. Most students are willing to try something new, and creativity is usually new. Instructors who voluntarily add creativity exercises to their courses will usually be enthusiastic. Picking good problems can be difficult because the instructor needs to know enough about the problem to know that it cries out for a creative solution, but without knowing the solution. (Instructors who know the solution have a very difficult time not teaching toward that solution.) Since pressure is real in the engineering profession, projects need deadlines. For motivational purposes it is important to have successes. Such things as a clever mechanism, a trick circuit, and a clever coupling of processes need to be celebrated as creative accomplishments. Detailed ideas most often delineate commercial successes since the development of a Xerox machine or the first introduction of a hand calculator occur rarely. Flowers (1987) suggests individual exercises before group exercises since group exercises introduce a whole new area of group dynamics.

5.7.3. Acceptance of Ideas

Foster creativity in students by accepting ideas and helping them build on ideas. This acceptance is an inherent part of brainstorming. In working with students both on class projects and as a research advisor, a professor who accepts ideas will foster creativity. But acceptance does not mean stopping the search for more ideas; instead, it means ideas are not turned down.

There are many ways to accept ideas. One way is never to criticize an idea (Hueter, 1990). Instead, suggest that the student work on it and report back to you on the result. If the idea works, then all is fine and good. If the idea does not work, the student will learn from the evaluation process. In either case the student will not be inhibited from generating new ideas.

A second method is to consciously use the PMI approach (de Bono, 1985; Gleeson, 1980). First, note the *plus* (P) aspects of the idea. Then note the *minuses* (M) in the idea. Finally, note the *interesting* (I) aspects that can be built on. Encourage the student to build on the idea to retain the pluses while eliminating the minuses.

Practice building on ideas. Outline an interesting, creative idea for the class. Then assign students homework building on this idea. Or have small groups work on an idea and have each student in turn add to the idea. When this is done, the rules of brainstorming (no criticism) apply.

Watch for creative solutions in homework assignments and tests (Felder, 1988). When one occurs, praise the student even if the final result is incorrect. Calling the student into your office and discussing the solution is one way to praise the student and to start building a relationship.

5.8. CHAPTER COMMENTS

We have tried to keep the information within the bounds of a chapter and at the same time to provide some concrete examples of what a professor can do to foster the creativity of students as well as to help improve their problem-solving skills. A large number of references are included for readers who want more information. If each professor spent five to ten minutes in class about once a week, we believe that students would become both better problem solvers and more creative engineers—certainly two goals worth striving for.

Creativity Examples: Possible Solutions

Example A. If all the toll booths going onto an island are closed, the toll can be doubled for cars leaving the island.

Example B. Reversal suggested slowing down the people. Mirrors were installed next to the elevators so that people could watch themselves (and others) while waiting for the elevators. Complaints plummeted afterward.

Example C. One possible reversal solution is to tell people to eat as much of anything they want, whenever they want but with one simple rule. When they eat, that is all they can do. No television, no conversation, no thinking about problems, no radio, no music, no reading, and so forth. They eat, and while they eat they think about what they are eating (Smith, 1975). One of the authors (PCW) can attest that this wonder diet works. It apparently works because the body gives a signal that it is full. When people do nothing but eat, they are much less likely to ignore this signal, and in addition, on this diet there is little worry about going hungry later. However, the diet is not simple since it requires changing habits, but it is a different solution.

Example D. Safety in numbers.

Example E. One in a million.

Example F. Since every player except one must lose a match, there must be 359 matches (Gardner, 1978).

Example G. Less thermal mass and cooling from top and bottom. Insulate the underside.

Example H. Snow sculptures.

Many other solutions are possible for G and H.

HOMEWORK

1. Develop several five- to ten-minute problem-solving exercises for an undergraduate engineering course.
2. Develop several five- to ten-minute creativity exercises for an undergraduate engineering course.
3. List thirty open-ended questions which are appropriate for a specific engineering course.
4. For a specific engineering class set up some example problems in the format of the strategy you are using.
5. Write a script for a brainstorming session in an engineering class.

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CHAPTER 6

LECTURES

One of the fundamental principles of engineering is to attack the critical problem that can make the most difference. In engineering education, improving or decreasing lecturing is arguably the critical problem; and the first focus on improving engineering education at all schools should be on improving or decreasing the amount of lecturing. Lecture used to be the most common form of teaching in engineering classes in the United States, and engineering professors lectured more than professors in other disciplines (Astin, 1993). Although Lattuca et al. (2006) found a significant increase in the occasional use of active learning by engineering professors, the decrease in lecturing was modest. For many professors, lecturing is synonymous with teaching. Although it can be an effective, efficient, and satisfying method for both professors and students, *the best way to improve lectures is to lecture less* (Eble, 1988; Ramsden, 2003). Yet many lectures do satisfy learning principles and are conducive to student learning at the lower levels of Bloom's taxonomy. Despite common misuse of the lecture method, a perusal of the *Journal of Engineering Education*, *ASEE Prism*, or the ASEE annual conference program shows few articles or presentations on lecturing.

We will first consider the advantages and disadvantages of lectures, and then methods for improving content, organization, performance aspects, and interpersonal rapport in lectures. Next, we'll explore special lecture techniques and special problems for large classes, and finally, look at the lecture as one component of an entire course.

6.1. SUMMARY AND OBJECTIVES

After reading this chapter, you should be able to:

- List the advantages and disadvantages of the lecture method of teaching.
- Discuss how one selects the content and organizes a lecture. Use these principles to prepare a lecture.
- List the performance characteristics of a lecture and determine how to improve your lecture performance.

- Discuss procedures for encouraging, answering and asking questions and practice improving your questioning skills.
- List what can be done to develop rapport with students during lectures.
- Discuss various modifications of lecture methods and explain how these modifications help lectures satisfy learning principles.
- Explain why large classes are more challenging than smaller classes and discuss what needs to be done differently in large classes.
- Explain how all the elements of a lecture course fit together to optimize student learning.

6.2. ADVANTAGES AND DISADVANTAGES OF LECTURES

Lecturing is a two-sided coin. An aspect of lecturing that is advantageous for an excellent lecturer can be a disadvantage for a poor lecturer. However, practically every disadvantage can be overcome if the professor makes an effort to overcome the problems. The following advantages and disadvantages are gleaned from our experience and from Eble (1988), Heywood (2005), and Lowman (1995). Some of the advantages of lectures include the following:

- *Audience focus*. The lecturer can be aware and responsive to a specific audience so that each student feels that he or she is being talked to as an individual.
- *Versatile and flexible*. There are many variants of lectures, and other teaching methods can be included within the lecture format.
- *Easily updated*. Unlike some other teaching methods, changing lectures is easy and inexpensive. Material which is not otherwise available can easily be included in a lecture.
- *Low technology*. If the lecturer is prepared to talk without slides or a document projector, little can go wrong other than the lecturer becoming ill. Even with slides or a document projector, the technology is relatively simple.
- *Acceptable and familiar*. Some students like lecture because it is usually nonthreatening and they can hide in the multitudes.
- *Can incorporate learning principles*. Learning principles which are not incorporated into the lecture itself can easily be included in the entire course package.
- *Can include assessment and rapid feedback*. Using clickers or other response systems, lecturers can obtain real time data on student understanding and provide immediate feedback.
- *Live contact*. Rapport with student is possible.
- *Can include hands-on or demos*. Real objects such as new materials or devices can be passed around in class. Simple demonstrations can be done in class—they are even more effective if student volunteers can collect data that the remainder of the class analyzes.
- *Professor-efficient*. Preparation time can be kept within reasonable limits.
- *Time-efficient*. Presenting to a large number of students is an efficient use of time.
- *Instructor control*. The lecturer is in control.
- *Anyone can lecture*. All new professors have taken lecture classes, and they can copy the procedures. The special knowledge required to lecture is low.
- *Potentially outstanding for motivation and for conveying information*. An enthusiastic lecturer presenting information in a variety of ways will help students learn.

- *Stimulating*. Lecturing can be exhilarating for the professor. The professor is clearly the center of attention (Ekeler, 1994)
- *Student learning can be high*. If clear objectives are given to students and good support materials are available, student learning in a lecture course of knowledge, comprehension, and application questions as measured by a content examination is equal to that of other teaching methods (Taveggia and Hedley, 1972) with the exception of mastery learning (Section 7.7.1).

Anyone can lecture after a fashion, but becoming an outstanding lecturer is difficult. If a professor does not know how to appropriately adjust lectures, then each of the advantages listed previously can become disadvantages:

- *Audience ignored*. Poor lecturers push on despite the pain and suffering which is obvious to all but the lecturer.
- *Inappropriate lecture form may be used*. Many professors are unfamiliar with the many variants of lectures and try to force-fit one form onto all circumstances.
- *Stagnation*. Although lectures are easy to change and update every semester, many professors don't bother. This is obviously a teacher problem and not the fault of the technique.
- *Murphy's law*. Although less technologically dependent than some other techniques, things can go wrong during a lecture. For instance, the projector can stop working or the microphone can malfunction—almost always at the most inopportune moment.
- *Passivity*. Like stagnation of material, acceptability of the method may lead the professor to ignore looking for ways to improve.
- *Few learning principles may be satisfied*. This is often the case in lectures with lots of content and little professor-student interaction. The worst problem is usually the passivity of students in lectures unless special efforts are made to keep them active.
- *Boredom*. A "live" presentation where the professor is boring, speaks in a monotone, makes no eye contact, pays no attention to the students, receives no student feedback, gives no feedback to the students, and is impersonal is "dead."
- *Inadequate preparation or over preparation*. Inexperienced professors often spend too much time preparing for lectures, and burned-out experienced professors may not prepare. One of the problems of lecturing is that there is no mechanism which forces adequate preparation.
- *False economy*. The economic efficiency of large lectures is abused by many universities. Student learning of higher-level cognitive functions would be significantly enhanced in smaller classes with more interactions.
- *Lack of individualization*. Since the instructor controls the pace, it will necessarily be too fast for some students and too slow for others.
- *Center of attention*. Some students pay a lot more attention to the lecturer than the content (Ekeler, 1994). They try to determine what the lecturer wants and what type of questions the lecturer is likely to ask on tests.
- *Anyone can lecture?* Unfortunately, the apparent ease of lecturing hides the fact that lecturing is one of the hardest teaching methods to truly master. In addition, what many professors have seen and are cloning are inferior lecture classes.

- *When it's bad, it's horrid*. Lectures can be outstanding but also abysmally bad. In addition, although lecturing is a good teaching method for conveying information, it is not well suited for higher-level cognitive tasks such as analysis, synthesis, evaluation, and problem solving.
- *Extremely stressful*. Lecturing can be an emotional trial for some professors. In extreme cases these professors need to find alternate teaching methods which are less stressful for them.
- *Lack of supporting material*. If clear objectives are not given to students and good supporting material is not available, then less student learning will occur compared to an alternate teaching method which provides these.

Probably more than any other teaching technique, lecturing is teacher-dependent. In short, lectures represent the best and the worst of teaching.

6.3. CONTENT SELECTION AND ORGANIZATION

The experts (such as Davis, 2009; Eble, 1988; Lowman, 1995; and Svinicki and McKeachie, 2014) are in surprising agreement about both content and organization. The lecturer should never try to cover everything—a major mistake made by inexperienced professors. Since students are supposed to spend two or three hours outside of class on homework and readings for every hour in class, leave major responsibility to the students. Thus, be selective.

1. Cover key points and general themes that guide the students' reading and help them build mental structures. These topics should be reflected in the course objectives.
2. Lecture on items that students find to be very interesting and are part of the lesson. Since lecturing is part performance, you might as well give yourself the advantage of choosing topics that students find particularly interesting.
3. Pick especially difficult topics or those that are poorly explained in the textbook. Tell the students that you will focus on these more difficult topics so that they will be able to do the homework better.
4. Discuss important material not covered elsewhere. Particularly in graduate-level courses, important new findings can be included in lectures long before they make it into textbooks. Lectures can be as up to date as the latest news on the Internet.
5. Include many examples. Students, particularly sensing students, love and need examples. Examples should include problems with numerical solutions, real world examples, and a modest number of short "war stories." However, telling students interesting, but irrelevant details reduces recall of the important points (Harp and Maslich, 2005).
6. Choose material at the appropriate levels of depth and simplicity. This is easier to say than to do when one has never taught the course before. Once you have taught the course, you can reduce the lecture coverage in areas where most students do well on tests and increase it in areas where students have difficulty.
7. Avoid *content tyranny*, which is letting the need to cover content dictate how you teach (Wankat and Oreovicz, 1998). Content tyranny invariably leads to poor student understanding as you race through huge amounts of material. Cover less, but with active students who learn.

Once the content has been chosen, put some thought into the mode of presentation. Everyone can use auditory, kinesthetic, and visual modes, and the more modes employed, the more content is retained (see Section 15.3.2). Unless special attention is paid to including other modes, the vast majority of lecturing will be in auditory (words written on the blackboard or in a PowerPoint slide are in the auditory mode). Yet most people prefer visuals and actually doing what they are learning. When arranging the content, include pictures, drawings, graphs, slides, computer visuals, and so forth. This may require some variation in the content and organization of the lecture.

What content areas can be left to readings and homework? Any content which experience shows students have little trouble with can be left out of lectures. If the textbook does an admirable job of covering particular areas, there is no reason to include this material in the lecture. When extensive details are required to solve problems, it is appropriate to outline the general procedure in the lecture, but leave the details to the textbook. Often, presenting a detailed example is the best way to present this material. Whenever material is left out of a lecture, be sure that the students are explicitly told that they are accountable for it. Clear written objectives help to ensure that students learn what they are supposed to learn.

A relatively simple organization is often best. Start with an attention-grabbing opener such as a question, a problem, a unique statement of fact, or a paradox. Then provide the students with advance organization: Tell them what you are going to tell them. It is helpful if this advance organization ties into the previous lecture. The main body of the lecture presents the content. To finish the lecture, summarize or tell them what you told them. It is helpful to briefly mention what will be covered in the next lecture.

You can organize the main body of the lecture in a linear, logical fashion. This type of organization is appreciated by the sensing students and does not prevent the intuitives from learning the material. A nonlinear, intuitive approach can also be effective, especially for upper-division classes, but is likely to confuse many students at lower levels. It may also be appropriate to present two or three topics simultaneously and to contrast and compare them. For example, transport phenomena can be presented in this form. Students need a hierarchical structure of knowledge, but they learn material best when they do some of the organizing. The result is that "a high degree of organization does not seem to contribute to student learning" (McKeachie, 1986). When students are seeing the material for the first time, use an inductive approach. Start with specific, concrete examples that are fairly simple. Analogies can lead to much more rapid student comprehension if the students understand the analogous theory (Meador, 1991). Then lead slowly into general principles. For students who have studied the material previously, a deductive approach can work; however, even in graduate classes an inductive approach is appropriate if the material is new.

The main body should be organized in clearly delineated parts. In a lecture using an inductive approach, the first part could introduce the topic with a simple example, the second part could consider a more complex example, and the third part could discuss the general principles. Each part should be ten to fifteen minutes long.

Between parts a short active learning break is needed (Bonwell, 1996; Heywood, 2005). Have the students *do* something different. A "talk to your neighbor" or small group activity (see Section 7.4.1) is particularly effective at re-energizing the students. For example, "Talk to your neighbor and see if you agree on the answer to this question." Even two minutes of rest or silent reflection is useful (Gibbs, 1992). Three two-minute breaks in which students clarify their notes with their neighbor's results in better short-term and long-term retention compared to straight lecture (Prince, 2004). This exercise has students think about what they are supposed to learn, and it provides a break. Breaks and re-energizing are necessary because most students have at most a 15-minute attention span (Gibbs, 1992; Wankat and Oreovicz, 2003). The active learning also helps to satisfy course objectives such as explaining phenomena. An example pattern for a 50-minute lecture class:

- Few minutes warm-up and housekeeping
- 10–15 minute lecture
- 2–4 minute break
- 10–15 minute lecture
- 5–10 minute student group exercise
- 10 minute closing lecture
- Few minutes closure and advance organizer for next class.

Pomales-García and Liu (2007) found that students want less lecturing and more engineering applications and examples. They also want more interaction and the chance to work examples in class. This would change the lecture format into an even more active course:

- Few minutes warm-up and housekeeping
- 10–15 minute lecture
- 2–4 minute break
- 10–15 minute lecture
- 15–20 minute student group exercise
- Few minutes closure and advance organizer for next class.

In planning the lecture think about the way students learn. If the scientific learning cycle (see Section 15.2) can be incorporated in some of your lectures, many students will benefit. If you consider that your lecture is part of Kolb's learning cycle (see Section 15.4), then the appropriate activities for periods when you aren't talking and appropriate homework activities will be clear.

6.4. PERFORMANCE

All lectures, including those on video or screencasts (see Section 8.2.2) are performances. Poor performances lead to poor lectures. Master performances can lead to outstanding lectures if the content and interpersonal rapport are also masterful. The good news is that professors who are content with being "competent" do not have to "perform." Professors who want to become master teachers need to develop skills in the performance aspects of lecturing. Since,

Preparation + presentation = performance

we will discuss the preparation and presentation of lectures.

6.4.1. Preparation for the Performance

Before your first class, check out the classroom. Does it have the equipment you expected (board, computer, projection equipment)? Does everything you need work? Are there enough seats for the expected attendance? If there are any problems, work to get the problems fixed before the term starts. Support staff will usually know who to call to solve problems. Collect the items you will need for every lecture (e.g., connector for laptop if you will bring your own computer, whiteboard marker or chalk, eraser, stapler, plain paper if you project your hand written notes with a document projector, and so forth). Bringing your own chalk and eraser may sound strange, but what will you do if they are missing and you don't have a backup? Put everything in a lecture bag that you automatically take to every class. If photo rosters of students are available, study them before class and bring them with you to class.

Actors and actresses start with a script and rehearse. You also need to prepare for the performance aspects in addition to preparing the content. The main part of the script is your lecture notes. These notes outline the content in a form that you find useful for live presentation. The lecture notes of good lecturers vary from three or four lines on a single index card to a completely written-out speech of several pages. Experiment with different forms of lecture notes to find what works for you. Lecture notes should include specific examples, visuals, and questions to ask students. One of the paradoxes of lecturing is that you must be prepared yet appear spontaneous. Under-preparation can lead to fumbling. Over-preparation can result in a rigidity that forces the professor to try to cover all topics in a prearranged order despite numerous signs from the audience that the lecture is not going well. Lectures need built-in flexibility so that the performer can adjust to the audience.

Just as playwrights put stage directions in their plays, you should include stage directions in lecture notes. These directions might include announcements and reminders to pass out handouts or to collect homework. Stage directions can also indicate pauses, where to ask questions, and breaks in the lecture for student activities. Alternative paths to provide flexibility can be included in the stage directions. Finally, stage directions can remind you to make any last-minute announcements (e.g., "Remember that the project progress report is due next period"). Stage directions are one way that you can help to ensure that the lecture is successful.

There is seldom enough time in a professor's schedule for a complete dress rehearsal for every lecture; however, there is time to do some rehearsing ahead of time. Obviously, reviewing and updating lecture notes shortly before the lecture are part of the rehearsal. So is a five to ten-minute mental preparation immediately before the lecture. If the class is in another building, this preparation can be done while walking over. Review the major points and "psych" yourself up for the lecture. One sign of a professional is the ability to be enthusiastic and interesting for the lecture hour even when the topic is not a particularly interesting one.

Arrange to arrive early at the stage door (the classroom). Check out the stage. Rearrange seats, clean the board, check that the computer and document projector are working, and get ready for the class. If the room is too small, too hot, or too cold, complain to the proper authorities. Eventually something may be done to improve classroom conditions. Teaching is often a low-budget production, and you must also be the stagehand.

In show business there are always warm-up acts before the main act. Professors can help warm up the audience also. A useful procedure is to write a summary of key points from the previous class and a brief outline of the current presentation on the board. This will help students start to think about the class and become mentally prepared to focus on the material. If the outline is written on a corner of the board and referred to throughout the lecture it helps satisfy the learning principle of guiding the learner (see Section 1.5). Surprisingly, a handwritten outline is more effective than a typed outline distributed to the class or a PowerPoint slide, perhaps because students are more active in processing the information (McKeachie, 1986). A second useful activity is to talk to students. Many students will talk to you before or after class but would never dream of coming in for office hours. You can be proactive and seek out students instead of waiting for them to come to you. Just arriving to class early sends the message that you are interested in and excited about the class. This interest and excitement can be contagious.

6.4.2. Presentation Skills for Lectures

When a play starts, the house lights dim, the curtain opens, and the audience leans forward attentively. A formal start to a class can focus the students' attention. Professors who use the computer or a document projector can dim the room lights and turn on the machine. This might be a useful start even if the document projector is used only to start the class with one page. Another possibility is to step out of the room to get a drink of water and then make a grand entrance to start the lecture. Some professors start writing on the board a minute or so before the class starts and then signal the class it is time to start by putting the chalk down and turning toward the class. One professor we know takes off his suit coat when it is time to start (and puts it back on to signal when the class is over).

This attention to small items such as how the class starts may seem like nitpicking, but it can make the difference between a great and an average performance. Also, not all the changes need to be made simultaneously. Institute a few changes every semester and slowly become more comfortable with performing in class.

Many plays start with an attention-grabbing ploy. You need to capture attention quickly.

1. Start with an appropriate comic strip on the document projector.
2. Start by saying, "I want to talk about next period's test."
3. Start with an appropriate newspaper headline such as, "Engineer gives million to university to improve undergraduate teaching."
4. Show a photograph or short video of a disaster appropriate to the class. Examples include the collapse of a bridge, a fire at a chemical plant, or a plane crash caused by failure of a part.

If you occasionally change the type of grabber, the students will wonder what you will do next and this increases their attention.

Once you have the students' attention, you need to retain it while the lecture proceeds. Change the tone, pace, volume, pitch, inflection, and expressiveness of your voice. A flat, unvarying monotone puts students to sleep, and sleeping students cannot be learning. Variety is also needed in gestures and in the format of the lecture. Even some variety in where you stand and how you interact with the students can be helpful.

Improving speaking patterns requires listening to and analyzing excellent speakers, practice, feedback, and then more practice utilizing the feedback. Examples of excellent speakers are readily available by watching television newscasters or listening to audiobooks. While listening, try to develop a feel for expressiveness, diction, and pace. One approach to practice and obtain feedback is to join Toastmasters and attend regularly.

Lowman (1995) recommends that professors record and analyze their speech. Since we hear our own speech through the bone structure of our heads, which is very different than how we hear the speech of others, no one likes to hear a recording of their voice. Listen for particular problem areas such as repeated verbalizations, such as "uh" and "OK," or a strident tone. Repeated words can be reduced once we become aware of them. Strident tones can be eliminated by focusing on breathing deeper. Improper articulation is a common problem that makes it difficult for students from different sections of the country to understand a speaker. This problem may be so much a part of the professor's speech pattern that it is not noticed even when listening to a tape. Have someone point out these problems to you in a friendly way. Articulation can be improved by practicing reading aloud (find a small child to practice on).

Professors commonly fail to project their voices. Remember that you should be speaking to the row behind the last one in the room. But projection is more than merely speaking louder—a practice that usually just wears out the voice. True projection begins with proper diaphragmatic breathing, which gives a base for the sound, and then follows with full articulation of the sounds: crisp consonants and full and liquid vowels. Like walking, speaking is too often taken for granted; but improvement in speech, just as in posture, step, and stride, can do wonders for one's personal as well as professional health. Self-help is valuable, but guaranteed improvement is best sought from a professional. If you are serious about improving your speaking voice, consult a professional voice coach (any university with a speech, audiology, or theater department has such an individual).

The manner in which the lecture is presented is also important. Should you read it verbatim?—Never! Untrained people are not able to read a lecture effectively. Use three-by-five cards? Rely on your memory? The best lectures are presented spontaneously after considerable practice. As a professor, you have enough command of your material so that notes or topical outlines will suffice to keep you on track. Finally, *never* read or recite the textbook to students. This is guaranteed to earn you poor student ratings.

Variety in mannerisms is just as important as variety in speech. Your gestures are also an important aspect of how you communicate, but they must appear natural and be neither wooden nor flailing. Gestures should be purposeful, such as those that indicate size, shape, emphasis, and so on. Purposeful gestures actually appear to help students learn (Jaffe, 2004). Nervous jabs that are out of synch with the message are not purposeful and distract the audience. One very effective but underused gesture is to walk into the audience. This gets the students' attention, allows you to make contact with those in the middle or back of a large lecture hall, and provides variety to your lecture. Since the lecture is a performance, you can plan effective gestures like this. Walk toward the back of the classroom when the lecture is dragging and something needs to be done to liven it up. Once you have tried an activity a few times, you will have added something new to your repertoire.

Even the barest stage has props. Professors have a table, podium, blackboard, and computer, plus whatever props they bring with them to the lecture. Props can also be used purely for dramatic appeal. Some professors bring in a glass of water and then drink the water while taking a break between two important topics. Sitting on the edge of the table conveys a very different impression than standing behind the podium. Bring in objects for educational purposes. A valve, circuit board, new alloy, bridge model, distillation column packing, or different types of crushed rock can all be an informative part of the lecture. These props have a greater impact beyond their educational value alone: They also provide variety and a chance for both visual and kinesthetic learning.

Classroom demonstrations during lecture can provide a concrete learning experience and the chance for discovery. The availability of new projection equipment has made it easier for all students to observe demonstrations, and more sophisticated equipment increases student interest (Pomales-García and Liu, 2007). Demonstrations do require setup time and a practice run before class.

How do you show students equations, figures, and words? We lean strongly toward relatively old-fashioned methods plus lecture notes. Either write on the board (white, green, or black) or use projection equipment that allows you to write as you lecture (document camera, tablet computer, or the old fashioned overhead projector). Nantz and Lundgren (1998) noted that technology should support teaching and should not force the teacher to teach in particular ways. "We found that using the computer as the course presentation vehicle is not the panacea we originally thought it to be" (Nantz and Lundgren, 1998, p. 53). Klemm (2007) considers slide shows to be a trap and suggests using slides for complicated visuals and equations with very few or no words. You should show at most a few slides at a time and then do an activity or write more material.

The most important props in most classrooms are the board and the projection equipment. Though commonplace and easily taken for granted, both can be used most effectively (1) as an external memory aid, (2) for emphasis, and (3) for visuals. When the outline is written in one corner of the board or on a slide, it can be referred to during the lecture to show the students where they have been and where they are going. The board or slide retains the information and serves as memory. The board can also retain an item that you later want to compare and contrast with another item. However, in a large classroom, writing on the board has to be quite large to be visible at the back of the room. Whatever is written on the board or shown on the screen is emphasized, and most students will attempt to copy the material. While doing this they may miss what you are saying, so putting too much on the board or slide is counterproductive. If you have some artistic skill, then the board can serve for visual presentations. But even without such skill, you can show graphs and simple schematic diagrams on the board. For more complex figures, slides can be made in advance, and copies of the figures can be made available on the web.

Neither the board nor projection is the best way to present large quantities of detailed information. Students may spend all their time trying to copy the material. In addition to not listening to the lecture, they invariably make mistakes in copying equations or complex diagrams. Even worse is showing pre-drawn PowerPoint slides in rapid succession. If the content requires that you cover a large number of equations or complex diagrams, hand out or make available on the web in advance partially prepared lecture notes or skeleton slides that contain the complicated equations, diagrams, and problem statements and have space for student notes. This greatly increases the accuracy of the students' notes and allows you to lecture somewhat faster. "Handouts are almost de rigeur for large lectures" (Gibbs, 1992, p. 28). However, more is not better—complete lecture notes encourage passivity (Gray and Madson, 2007). If your handwriting is legible, you can use a tablet computer to write on the skeleton slides. An alternative is to use a skeleton PowerPoint slide and type additional notes on it during the lecture. Use a different color for the type so that students can focus on the new material rapidly. Since typing distances the lecturer from the audience, use this approach *very* sparingly.

An alternate solution is to change the content selected for presentation. If the goal is to produce engineers who can do abstract mathematical proofs, then the lectures, homework, and tests are rightly focused on this activity. If the goal of the course is to have students become good problem solvers, then it makes more sense to spend time solving problems during lecture.

The biggest difficulty in using a board is the loss of eye contact while writing on the board. This is less of a problem with projection, but the lecturer must occasionally glance at the screen to check the message the students are seeing. Blocking the view of the students may also be a problem with both the board and the document projector. Most professors go too fast when using PowerPoint slides, and students find PowerPoint decreases their interaction with the professor (Pomales-García and Liu, 2007). PowerPoint should be reserved for seminars and for screencasts (see Sections 8.2.2 and 8.2.4) that the students can watch multiple times. One advantage of the board is that material can be left on some portion of the board so that students can go back and copy something they have missed. Projection can also retain information if the classroom is equipped with two document projectors and two screens. Once one document is finished, it should be transferred to the back-up projector. We suggest that new professors try both document projectors and boards. Obtain student feedback on what can be done to improve both procedures. Then, select one method to focus on and become an expert with this technique.

Eble (1988) states that the skillful lecturers he observed "were above all keenly aware of and responsive to their audiences." Remember that lecture is a live performance. Watch and read the audience. Are they generally engaged with the material or is their attention wandering? If they are showing signs of boredom, what can you do to shift gears? If someone is clearly confused, try asking if you can help (see Section 6.5.2). The audience provides feedback by both verbal and nonverbal behavior. On rare occasions the message you have from the students is that everyone is focused on you and you have the class in the palm of your hand. Enjoy the moment and try to remember what you did or what the magic content was so that you can do it again.

When something starts to go wrong, the trick is to observe and respond to the problem quickly. After many failures, we finally realized that continuing the lecture and perhaps talking louder does not work. Perhaps you have overstayed the fifteen to twenty-minute attention span of the students and it is time to go to a group activity or have a question-and-answer session. Clearly shift gears and do something that forces the students to engage the material actively. Consider doing one of the following:

- State "Ask me questions." Be clear that this is question time, not an interruption of the lecture. Then silently wait for questions.
- Switch to a Socratic approach and ask the students questions.
- Ask the students to summarize the most important point in the lecture on a piece of paper.
- Provide a two-minute rest break.
- Give a short quiz (see Section 6.7.1).
- Do a pair or group activity (see Chapter 7).

After a few minutes, you can switch back to lecturing with renewed student attention.

Responding properly to signs of audience problems and preventing such problems before they occur requires timing. Good timing means knowing the appropriate time to do something.

Timing is an art that can be learned. If you are good at telling jokes, then you have a sense of timing that can be used in your lecturing. In a lecture it is sometimes appropriate to stop when a student has a question, and it is sometimes appropriate to ask the student to wait until you can come back to that student later. Sometimes you have to speed up, sometimes slow down, and sometimes pause. When a student becomes a bit aggressive and hostile, sometimes it is appropriate to hash out the problem in class, but normally it is better to discuss the issues privately. All of these instances are examples of timing. Good lecturers and good actors develop a sense of timing with experience. Pay attention to what works and record what doesn't work so that next time the timing can be improved.

Humor can also be part of a professor's repertoire. If you can successfully tell "canned jokes," then use them to start the class or break the routine. If you can't tell a joke, don't. Many professors successfully use comic strips on transparencies to start a class; however, the strip should be appropriate and in good taste. Some professors' style of humor is spur of the moment and based on things that happen in the class. Again, if you can do this successfully, it can help keep the attention of the class. If you can't, don't. Even if you can successfully add humor, avoid overkill. Finally, humor should never attack students, be hurtful, or be offensive (Powers, 2005).

A final note about performance: Some people have a flair for being dramatic. A little drama can help keep the class interested. Build up to the lecture's conclusion and at times slip in an unexpected conclusion. A bit of challenge in the class can be fun for the students, particularly if it is nonthreatening. Ask dramatic questions or make dramatic statements. For example,

- What did X do that made him one of the most revered engineers of his era?
- There is one pearl of wisdom in this class which will make you rich and famous if you follow it. Your challenge is to find this pearl.
- In today's class we will discuss misunderstood phenomena in electricity and magnetism.

A sense of timing is needed to let the drama build. Do not answer your question or explain the statement immediately. Let the students search and try to puzzle out the answer. Student learning will be much deeper if they can determine the answer for themselves, even if they beat you telling them by only a minute.

6.5. QUESTIONS

Questions offer an opportunity to work on understanding content and developing rapport. Students asking or answering questions are active and thus are satisfying one of the learning principles discussed in Section 1.5. Questions also serve as a break in the lecture and allow some students a chance to catch up in their note taking. Finally, the instructor's availability to answer questions is one of the factors that students implicitly include in their overall ratings of instructors (see Section 16.4).

6.5.1. Answering Student Questions

We strongly encourage students to ask questions in class. If many students are confused, you can clarify the issues for them simultaneously. Thus, during the first class period we make it clear that student's questions are not an interruption of the lecture. Some professors prefer to control student questions and have students ask only at specified times. Pause fairly frequently during the lecture and ask if there are any questions. Then, give the students time to pose an intelligent question. The appropriate length of a pause requires a sense of timing, but it is longer than the couple of seconds many lecturers use.

When a student asks a question, accept it positively and then rephrase it so that the student can be sure that you understand the question and so that the rest of the class can hear it. Examples of positive reinforcement for asking questions include:

- Good question.
- That's very insightful of you, Karen.
- Bob, you're following me exactly because that's my next topic.
- Good, I was waiting for someone to ask about that.

Restating the student question can be a challenge. When students are confused, they may have difficulty even phrasing an intelligent question. Asking a question under these circumstances is an act of bravery (which is one reason the student should receive a positive response). Make your best guess as to what the question is, even to the point of asking the student if that form is reasonably close to what he or she wants to know.

Various responses to the question are now possible. Since students usually prefer direct answer, it's best to give direct answers most of the time. If the question opens up a new topic that will be covered in a few minutes, ask the student to wait, and if not satisfied in a few minutes, ask again. When we use this technique we try to remember to ask the student later if the question had now been answered. The student can be referred to the book; however, this works best if the entire class is asked to find the answer in the book immediately. Otherwise, "Look it up in the book," comes across as a very negative reaction to a student's question. The question can be posed to the class to determine an answer. This works well in classes where discussion is commonplace. If the question is quite involved or the student clearly does not understand your answer, ask him or her to see you after class. This is often appropriate when the student wants to see the complete solution to a problem and time is not available to do this. Another response is to ask another question to try to lead the student to the correct response to the original question. Unfortunately, this approach tends to inhibit student questioning since it puts the student on the spot. Finally, if you do not know the answer, the safest response is, "I don't know, but I'll find out." Instructor honesty helps increase rapport with the students.

Students are often very hesitant to ask questions. A method that elicits excellent questions is to have the students sit in small groups. Give each group one 3×5 card and tell them to write one or two questions that the group agrees are reasonable questions on the card. Collect the cards and answer questions in the order the cards are turned in. This procedure works partly because putting the students in small groups and having the question written on a card makes the question asker anonymous. In addition, written questions are often briefer and easier to understand than oral questions. This method is one of several related techniques called "a one minute quiz." However, obtaining the questions takes 3–5 minutes and answering them can take quite some time in a large class. An alternative is to start the next class by answering the questions.

A closely related method is to ask individual students or small groups to write what the "muddiest point" of the lecture was. Students turn in their comments at the end of class, and the professor starts the next class by addressing these points.

6.5.2. Asking Students Questions

There are several advantages to asking questions during class (Hyman, 1982). Questions can provide a break in the lecture, which helps to keep the students active. Questions also provide feedback about what material is being understood. Questions provide an alternate way to emphasize particular points, clarify difficult concepts, and review material. Rhetorical questions are often useful for this purpose or for highlighting key questions. Questions can be used as examples of possible test or homework questions. They can also be used to start a discussion or to encourage student questions. Questions can be used to help maintain discipline or keep students awake. Some professors structure their entire teaching style around questions and use a Socratic style instead of lecturing. Currently, asking questions and obtaining responses with clickers is fashionable (see Section 6.7.4).

If you often ask rhetorical questions, then some sort of signal is needed that the question is for the students. For instance, "Now I have a few questions for you." Even if you never use rhetorical questions, it's useful to let the class know that you are going to shift gears away from lecturing. "Let's take a break from the lecture and try some questions."

Students and new professors often believe that the questions asked by the professor must be spontaneous. A few are, but most are planned. Posing a good, clear question that requires some thought to answer but is not beyond the ability of the students requires time and effort to prepare. Prepare ahead of time and write these questions in your lecture notes. If a good question arises spontaneously, try it and record it in your notes after class.

A good question should be relatively short, clear, and unambiguous. Only one question should be included; that is, do not run a string of questions together. If you want to ask a string of related questions, then ask one at a time and get a response before proceeding. Otherwise, you are likely to confuse the students (Hyman, 1982). The question can be at any level of Bloom's taxonomy, and if you want students to become proficient at all levels, then you must ask questions at all levels. In some cases you may want to write an equation or draw a figure on the whiteboard or on a slide to frame the question.

In engineering it is appropriate to ask questions that require a modest amount of algebraic manipulation or numerical calculation. Tell the class to take out a piece of paper and a calculator, tablet, or smart phone. Then write key elements of the question on the board or use a pre-prepared slide. Students can work individually or in groups. Questions can range from very simple single-answer questions, such as unit conversions, to unusual situations where basic principles can be used to obtain an answer to open-ended questions.

Usually, it is best to ask the question of the class as a group and then pause. In this way, no one knows who will answer it and most students will try to develop an answer. If you are using the question to help keep a student awake, then you might want to preface it with the student's name. Even students who are close to falling asleep will respond to hearing their name. After asking the question, pause. The pause is critical and for most teachers is much too short. It takes time for students to formulate an answer.

There are a variety of ways to field students' responses to questions (Hyman, 1982). If the student's answer is correct, repeat the answer so that the entire class can hear it and offer praise: "Excellent" or "You're absolutely right." This gives the student strong positive feedback and tells the rest of the class that the answer is correct. If several students are straining to answer, you can call on several without responding to each individual answer. Then respond in general to all of the responses. You can also build on a student's response. "You're correct about the fluid flow. But let's consider the mass transfer in more detail . . . " The continued detail can consist of an explanation or additional questions.

What if the answer is wrong or partly wrong? For many professors the immediate reaction is a "Yes, but . . . " type of response. Unfortunately, this sends a negative message. It is better to be more straightforward about those aspects which are wrong. Some possibilities include:

- You're right about aspect X but wrong about Y. Let's explore Y in more detail.
- I think that you have misinterpreted my question. Let's try it again. (Use this type of response only when you really believe the student has misinterpreted the question.)
- No, I don't think that you have the right idea on this. But let's look at why you might have answered that way.
- Explain how you developed that answer.
- How many students think this is correct? How many think this is incorrect? Why is it correct or incorrect? (Use these responses occasionally for both correct and incorrect answers.)

Should you call on students who volunteer to answer, or should you call on all students at some time during the class? There are advantages and disadvantages to both options. Volunteers are likely to be more articulate and are more likely to have an answer. In addition, calling only on volunteers makes the class safer for students, since they know they won't be called on when they don't volunteer. If you call on volunteers, spread out which volunteer is called on. Call on students who seldom volunteer, when they finally volunteer, to help them participate in class. The disadvantages of calling only on volunteers are that some students will never participate and students who decide not to volunteer probably won't try to solve the problem independently.

Calling on students at random or with some prearranged rotation schedule keeps all the students "at risk." The professor can force more students to participate, but the anxiety level in the class is likely to increase. In addition, the percentage of wrong answers or "I don't know" answers will increase. The number of correct answers can be increased by telling students to check their answers with their neighbors before calling on a student. If class participation and the ability to answer questions and present arguments in public are important in your class, then some type of strongly encouraged participation is needed. One modification used in law schools is to allow students to put a slip of paper with their name on it on the desk if they are not prepared to discuss that day's class.

Some professors use a modified Socratic approach. Short periods of explanation of the material are interrupted by question periods. The professor calls on particular students and makes sure that everyone is called on at least every other period or so. This is most effective in medium or small classes (less than about fifty students). Call each student by name. In addition, professors who become adept at reading students' nonverbal clues can choose to call on students either when they are ready or when they are not ready to respond. This procedure does help most of the students improve their ability to think and respond under pressure, which is useful for engineers. Depending on the professor's attitude and style, the Socratic approach can be either moderately or very threatening to students.

There are gender differences in asking and answering questions (Tannen, 1990). Very generally, men are more comfortable speaking in public, while women are more comfortable speaking in private. Thus, the men in the class are more likely to ask and answer questions regardless of how well they know the material. They are also more likely to challenge the professor. Professors are then faced with a value question. Should they let people keep the roles they have been socialized into or should they try to change them (the men, the women, or both)?

6.6. BUILDING INTERPERSONAL RAPPORT IN LECTURES

Interpersonal rapport is the second dimension in the model of good teaching shown in Table 1-5. Although large lecture classes are not the ideal vehicle for building rapport, professors can do many things to increase rapport with their students. The most common item mentioned by students when asked what professors could do to make them feel comfortable was "know my name" (Pomales-García and Liu, 2007). A student survey found that 90% of faculty who are considered supportive know students' names, while only 20% of non-supportive faculty knew their names (Daly et al., 2012).

6.6.1. Student Contact Before, During, and After Lecture

The few minutes before class provide an excellent opportunity to make contact with students even if you all have to wait in the hall while the previous class finishes. Greet students by name: "Hi Susan, how are you doing today?" "John, did you get that problem we were talking about yesterday?" Early in the semester when you don't yet know every student's name, it is not impolite to walk up to students and ask them their names. Many students will come up before or after class and ask if they can ask a question. Responding in a friendly way using the student's name sends the message that you are friendly and you know who they are—"Yes Bob, what's the problem?" (Note: In our examples we use first names. Some professors are more comfortable and think it is more professional to be more formal and use the student's last name. If you are not sure, consult with colleagues in your school.)

Once the lecture starts there are a variety of ways to make contact with students. The most obvious and direct way is by eye contact. In some cultures it is considered impolite to look a person in the eyes when speaking, but in ours the opposite is true. Establishing eye contact with students not only lets them know that you're aware of their presence but also makes them feel that you are speaking to them and not just at them.

If a student has come up with a thoughtful question or a clever solution to a problem, share it with the class by naming the student: "Jennifer Watkins has come up with a very interesting paradox that I thought everyone would be interested in." This shows the student that you really did pay attention and thought that her idea was important. If student presentations are part of your class, you could also ask the student to present her paradox and the resolution to the class.

Recognizing student feelings during the lecture can help increase your rapport with students. For example,

"I know several of you are angry about the test. You felt that you could have done much better if you'd had more time. I agree that the test was long. I'm working on getting more time for the next test."

"This point must be confusing. Can all of you who are *NOT* confused please raise your hand. Yes, I was right, many people are confused."

Note that a large percentage of students will not raise their hands regardless of the question. Thus, you can often make most of the class look like they are on one side of the question or the other by changing the phrasing of the question.

Part of the trick of developing personal rapport is presenting a part of yourself in the lecture (Micari and Pazos, 2012). Usually, this sharing will be related to the course or professional topics. Sharing your excitement and enthusiasm for the subject is always appropriate, "This is really great stuff." If you had difficulty learning a topic when you studied it for the first time, share this with the students also. If you will miss a class because of a professional society meeting, share with the class the importance of the meeting and what you expect to learn there. It should be obvious that it is the instructor's responsibility to arrange to have a qualified person meet the class or arrange a makeup session for the class that will be missed. Periodically encourage students to come in to office hours.

Although it is helpful for students to see you as a real person with a family, the classroom is not a therapy session. However, when there are teachable moments or a chance to connect with students; sharing a bit of your personal life is appropriate.

Another prime time to talk to students is after the class is over. Stick around for a few minutes and answer students' questions in the classroom or in the hall. If a cluster of students is waiting to talk to you, turn first to the student who rarely says anything in class. He or she is the student who needs the most encouragement. If many students are waiting to talk to you after class, consider shortening the lecture by five minutes to allow more time for informal questions.

6.6.2. Other Methods of Increasing Rapport with Students

There are a number of ways that students can be become involved in a lecture class. One method is to have a group of volunteers who meet regularly with the professor to provide feedback (Svinicki and McKeachie, 2014). The student volunteers can be told to talk regularly to other students and obtain feedback. The volunteers quickly learn that they can be very blunt with feedback since they are merely reporting what someone else told them. If you are willing to make some adjustments, this procedure can help class rapport since the students can see that their feedback makes a difference and that you care. Obviously, you have the opportunity to get to know the volunteers well. The entire class can also be asked to do a formative evaluation early in the semester, and you can respond to these comments (see Section 16.2.).

You can increase rapport by being sensitive to nuances in relationships with students. Clearly, yours is the power in this relationship, but using egalitarian language in making assignments can promote student independence (Lowman, 1995). For instance, instead of ordering students to do a homework assignment, you might say, "Those of you who do problems 6, 7, and 9 will find that they will help you in Friday's quiz." Sharing the course objectives with the students can also make assignments seem rational. Thus, you might explain the reason for an assignment, "This reading will help us reach our goal of being able to . . . " When content that is not technical will be assessed, sharing ABET criteria (e.g., criteria 3d and 3f–3j, Table 4-4) helps the students understand the reasons for the assessment.

When possible give the students some choice. Projects can be very effective, particularly for upper-division students, because they give students a choice as to what they do (see

Sections 11.5 and 12.2). In elective classes students can also be given a choice, within limits, of what material to cover (Wankat, 1981). If the examination dates are not carved in stone, students can be allowed to vote on the dates. Giving the students choice will often promote intrinsic motivation and increase the students' sense of personal responsibility for learning.

Other special procedures that can be used to help build rapport are discussed in the next section. A variety of one-to-one contacts outside the classroom will help build rapport (see Chapter 10). Other aspects of the entire course can fit together so that rapport with students is enhanced (see Section 6.9).

6.7. SPECIAL LECTURE METHODS

Lectures can be modified to include almost all the learning principles. We will briefly discuss four of the many possible modifications.

6.7.1. Pre-Lecture or Post-lecture Quiz

Students need to pay attention, and they need feedback on what they have learned. Both of these principles can be included in a lecture format by regularly giving short pre- or post-lecture quizzes. One way to do this is to give a quiz during the last ten minutes of class (Gray and Madson, 2007; Peck, 1979). Since the quiz covers material that has just been presented in the lecture, open book and open notes are preferable. Usually the quiz will consist of one short-answer problem that can be solved in a few minutes. The extra time is necessary since students who have just learned the material will be inefficient problem solvers. Of course, quizzes do not replace the need for longer problems in homework assignments and for a few longer tests.

In large classes daily or weekly quiz grading can become a significant burden. However, since the quizzes reduce the amount of homework problems that need to be assigned the increase in total grading burden may be modest. Also, if you are satisfied with awarding no partial credit, quizzes can use multiple-choice problems, which greatly decrease the grading chore. When there are numerical answers, a method for developing multiple-choice tests which eliminates many of their usual drawbacks is presented in Section 11.2.3. To start the next period spend a minute or two going over the solution to the quiz problem and use this as a springboard for discussion. The next lecture will then build on this base.

This type of approach has several advantages. When students know that they will be tested at the end of the period, they will pay attention to the lecture and may even read the textbook in advance. They will also ask questions during the lecture because they know they cannot wait until they get home to puzzle out a confusing point. The students also practice every class period that has a quiz, which requires them to be active, and then they receive feedback either immediately or in the next class period. You also obtain feedback immediately and know if the students are learning the basic material. The very frequent quizzing reduces the importance of each quiz and thus reduces test anxiety. Test anxiety can be reduced further by dropping the lowest 10 to 15% of the quiz grades. Although you have less time for presentation of new material, some of this is gained back since less frequent hour examinations need to be given. The large number of quiz scores makes grading at the end of the semester easier, and every student knows where he or she stands in the class.

Obviously, this procedure can be varied significantly while retaining the advantages. Some of the quizzes can be assigned as group efforts, or quizzes can be given every other period or once a week instead of every period. A short derivation or essay problem can be given instead of a numerical problem. And occasionally the quiz problem can be a review problem instead of a new problem. If the students do very poorly on one quiz, the quiz can be repeated.

An alternative "one-minute quiz" has been widely adopted in nontechnical areas. In this form of one-minute quiz students are asked to write one sentence answering some variation of the question: "What was the most important concept covered in lecture today?" This can be open book and open notes and, if desired, open neighbor. A one-minute quiz actually takes a few minutes. Although the one-minute quiz is not graded, it has many of the advantages of a problem-solving quiz and can be used as a replacement occasionally.

Pre-lecture quizzes are useful to encourage students to study before class, and are often part of a flipped class (Section 7.2). Pennebaker et al. (2013) gave short internet based quizzes at the beginning of class. The quizzes were half on the readings and half on previous lecture material. They found an almost statistically significant ($p = 0.06$) increase in student learning and improved grades in all classes.

6.7.2. Guest Lecturers

If the world expert on a topic has an office next door to you, perhaps you could invite him or her to present one lecture. Engineers from industry can give an industrial flavor that most professors cannot duplicate. Lectures from an industrial perspective can be valuable in any engineering class and not just in design courses. Many universities also have "old master" or "outstanding alumni" programs which invite interesting people back to the campus. These individuals are delighted to talk to students, and students usually appreciate the break in the routine provided by guest lecturers.

Ideally, a guest lecturer will integrate his or her presentation neatly into the course (Borns, 1989). An engineer from industry could come in and talk about the design of heat exchangers at the point where the students are ready to cover this material and will benefit from the engineer's expertise. If the guest lecture is to be integrated into the course this tightly, you need to be sure that it is clear what the students can do and what is to be covered. Give the lecturer copies of the syllabus and reading assignments so that he or she can develop a lecture at the appropriate level. If any special equipment will be needed, be sure that everything is available and in working order.

Guest lecturers need to be selected carefully. Find someone who has the special expertise that you want; then check around to find out how good a speaker the person is. Once you have found someone who does a good job, invite them back.

In general, be present when a guest lecturer speaks. This is particularly important if the guest lecture is presented via video or Skype. Your presence also sends a message to the students that the material is important; furthermore, you may learn something. An exception occurs when you find someone to substitute while you are away on a trip. Substitute lecturers usually cover the normal course material. Be sure to tell the substitute exactly where you stopped the period before, and afterward find out how much he or she covered. Delineate for the substitute exactly what material should be covered. The best substitute to use is someone who teaches the same course in different semesters. If you arrange to trade substitutions, the workload tends to even out, and no one feels taken advantage of. Often the class TA is asked to present a lecture while the professor is out of town. This can be a good experience for the TA, but not necessarily for the class. Sit down with the TA ahead of time and go over the content you want covered in detail. If the TA regularly attends the lecture, he or she will not be rusty. After you return, discuss the TA's lecture with the TA so that the lecture can be a learning experience. Regardless of who does the guest lecturing, be sure to thank them in writing for their efforts. If the students comment on how much they enjoyed the lecture, be sure to mention that in your letter.

6.7.3. The Feedback Lecture

The feedback lecture is a technique developed by Osterman at Oregon State University (Osterman et al., 1985). Students first receive a study guide that outlines how they should prepare for each lecture. Then during the lecture they receive a lecture outline as a further guide. The professor lectures for roughly twenty minutes. Small student groups then discuss an important question and turn in a response sheet. The professor briefly discusses the discussion question and then lectures for the last twenty minutes of the period. Homework assignments provide further practice.

This procedure formalizes the use of many learning principles. Students receive clear objectives in the study guide, and their learning is carefully guided by the study guide. The lecture outlines help them organize the material. The group activity in the middle of the lecture requires that students be active and makes the class more cooperative. Feedback occurs from other students in the group discussions and from the professor both during the group activity and after the response sheets are turned in. Some teaching of students by other students often occurs during the group discussions. The discussion questions are chosen to be particularly thought-provoking to pique the students' interest.

Such a formalized procedure obviously requires a fair amount of advance preparation, so it's unlikely the professor will arrive in class unprepared for the lecture. This method also motivates students to prepare for each class since they know that they will have to do something in each class. Students are thus less likely to procrastinate. Obviously, components of the feedback lecture and the post-lecture quiz can be combined in a variety of ways.

6.7.4. Personal Response Systems ("Clickers")

Personal response systems (colloquially known as "clickers") have rapidly become quite popular on campuses (Fies and Marshall, 2006; Bruff, 2009) including in engineering (Chen et al., 2010; Falconer, 2007; Siau et al., 2006; Roselli and Brophy, 2006). Clickers provide immediate feedback in lecture, help keep students from being overly passive, and are easy to incorporate in a lecture.

Many institutions have installed central receivers and the necessary software in large classrooms. Usually, the cost of buying the individual clickers is left to the students. Before deciding to use clickers, test the system in your classroom. Students become very frustrated if their answers are not recorded. The system should have a positive method that allows students to determine that their answers have been received—usually this is done by projecting a grid that shows which clickers have responded. Doing a clicker system test at the start of every class also provides an on-time attendance record.

Clickers record student responses to multiple-choice or true-false questions and provide averages for each answer in real time. That is all that clickers do. Of course, in a small class you can obtain the same information without needing technology, and using clickers in a class of 10 to 15 students would be kind of silly. How do you use this tool to improve a large class? First, by asking questions and rewarding student responses with a small number of points, students are forced to be at least minimally active. Second, questions can easily be asked that check if the students have done the pre-class assignments, for example in a flipped course. (Flipped courses are discussed in Section 7.2.) Third, questions that require thought or that explore common misconceptions encourage student engagement in the lecture and provide immediate feedback to the instructor on student understanding (Beatty et al., 2006; Falconer et al., 2009). Most importantly, difficult questions provide a vehicle for peer tutoring (Mazur, 1997). When a substantial number of students have the wrong answer, you can tell the students to discuss the question with their neighbors to see if there is a better answer. The opportunity to change their responses, particularly where points are involved, will motivate most students to engage in these small group discussions. Properly used with appropriate questions and required student peer instruction, clickers help students understand what they do not know (Roselli and Brophy, 2006) and result in increased student learning (Crouch and Mazur, 2001). Another advantage of clickers is they lower the resistance of traditional teachers to transforming to a more student-oriented pedagogy (Kolikant et al., 2010).

There are, of course, alternate methods of providing rapid feedback in lecture. Chen et al. (2010) found no significant difference between sections using rapid feedback from flash cards and those using clickers for rapid feedback. A separate experiment compared rapid feedback with clickers to a control section without rapid feedback. The rapid feedback section was statistically better. The instructor prepared the questions before each class and decided where to place them in the lecture. He observed that the students focused on the questions and worked to answer them despite the lack of a grade. The conclusion was that rapid feedback in lecture is very useful, but the form of the rapid feedback is irrelevant. Bursic's (2012) results were slightly different. She used clickers but did not include peer instruction. Clickers improved the learning environment and the students' perceptions of how much they learned. However, an actual increase in learning was not observed.

Unfortunately, clickers, like any other tool, can be misused—for example, by exclusively asking questions at the knowledge level of Bloom's taxonomy. We suggest that novices attend the class of a professor who has won teaching awards using clickers to see one effective method of using clickers. Another misuse occurs when students subvert the system and cheat on clicker quizzes. If the number of points involved is low and the penalties for cheating are substantial, there will be little cheating (Lang, 2013).

A different rapid feedback method for large classes is to use "Lecture tools" (http://www.lecturetools.com/) that allow students to text in questions live during the lecture period. A TA reviews the questions and shares the most relevant ones with the professor.

6.8. HANDLING LARGE CLASSES

Very large classes (more than 100 to 150 students) have some special characteristics that make them different from small classes. The challenge is to make student learning as close to equal to that in a small class as possible. Our discussion of handling large classes leans heavily on the papers by Hickman (1987), and Middleton (1987); book by Davis (2009); and our own experience.

Large classes require more preparation, more structure, more formalized procedures and more rules than small classes. In many ways good teaching is good teaching regardless of class size, but unfortunately, large classes magnify any problem. Consider preparation. If several hundred copies of a handout or test are to be distributed, you can't wait until ten minutes before class to have the copies made. So more planning is required. Arrangements must also be made to distribute the several hundred handouts or tests efficiently; thus, you must assign the TAs and/or your secretary the responsibility of being in class to help with these duties. We now post handouts and assignments on the web and, except for the syllabus, no longer hand out paper copies in class. Lecture preparation must also be thorough. In small classes professors quickly develop rapport with the students, and the professor can come in less than fully prepared on occasion. In large classes inadequate preparation is more obvious and students are much less forgiving.

Large classes need to be more structured. The syllabus needs to be detailed and available on the first day of class. Examination dates *must* be listed. In effect, these dates become a contract with the students and it becomes quite difficult to change them without causing major problems for some students. The textbook must be ordered early and be more carefully selected since some students will rely heavily on it. Course supplements may be necessary and have to be prepared well in advance. The grading scheme needs to be formalized and set forth at the beginning of the semester. Since there will be students you do not know well, grading becomes more impersonal. Rules for missed examinations and late assignments need to be stated and followed. There are likely to be more problems with uninterested students who are talking, texting, or sleeping. Formal rules are required so that the students know what acceptable behavior is. An attendance policy needs to be set. Since there is a good correlation between attendance and grades, attendance should be encouraged. It is always useful to keep track of who attends, since poor attendance often explains poor grades, and poor attendance always reduces the professor's tendency to be lenient in grading. Either assign seats and have a TA take attendance or have students sign in with clickers.

Unfortunately, increases in class size often do not mean an equivalent increase in the number of TAs. In this situation there must be a decrease in the number of items graded. It is possible to grade only a subset of the homework assignments and to use multiple-choice problems for parts of tests. For many courses undergraduate graders can do part or all of the grading. In our experience undergraduate graders do as good a job on average as TAs. Just keeping track of grades becomes a burden with large classes. Use an electronic spreadsheet and make the current scores for every student available using a system that protects students' privacy (e.g., Blackboard). Make it the students' responsibility to check for clerical errors.

Cheating is more of a problem in large, impersonal classes (see Chapter 12). Thus, more care is needed in administering the examinations (see Section 11.2.4). It may be necessary to have two versions of the test if the class is too large for students to sit in staggered seats. Care must be taken that all tests are collected and that there is no cheating during the chaos of hand-in time. An alternative is to have a clear, enforced, pencils-down policy when the test period is over. Uniformity in grading is very important, and each problem needs to be graded by a single person. Rapid feedback is important, but more difficult to achieve in large classes. Written regrade requests are a necessity (see Section 11.3.3).

Small classes, particularly those with fewer than fifteen students, develop interactions between students and between the professor and students with very little formal effort by the professor. This is not true in large classes. A structured period for interactions needs to be provided in the lecture plan, either by small group discussions or a question period. Informal meetings before and after class become more important, although not all students can be accommodated. Some type of formal procedure, such as a seating chart or photographs of every student, is required if you are to learn the students' names. Rapport with students is essentially impossible if you do not learn the names of the students.

Students in large lectures can be assigned seats in blocks corresponding to their laboratory or recitation sections. They will feel less isolated since they see the same classmates more often. Set aside two minutes early in the semester to have students introduce themselves to their neighbors. If cooperative group activities are used (see Section 7.4), the students will be working with others they know. The laboratory or recitation section TAs can also attend the lecture and sit with their students. This provides someone close by to answer questions. And it will tend to reduce disruptions since there is a person in authority close by.

Overall, teaching large classes is much more of a challenge than teaching small classes. Small classes can be quite a bit of fun, but teaching large classes is hard work. To do outstanding teaching in a large class is the mark of a master teacher—a rare professor.

6.9. LECTURES AS PART OF A COURSE

Lectures are only a part of the entire course, and it is the entire course that determines how much students learn and what their attitudes will be. It is important that appropriate learning principles are satisfied for the entire course, because it is not feasible to satisfy all of them in the lecture alone. We will discuss the list of what works from Section 1.5 and consider how each item can be satisfied in a lecture-style course.

The course objectives can be covered in lectures. Probably the most effective way is to hand out a sheet of objectives for each section of the course and discuss the objectives in lecture. This helps guide students. The lecture is the appropriate place to develop a structured hierarchy of material and the most appropriate place to use visual images. The textbook serves as a useful adjunct for these tasks.

Although a modest amount of practice and feedback can be provided in a modified lecture, homework and tests serve best for providing practice and feedback. Even if homework is not graded, it is still necessary to provide feedback. This can be done by making solutions available to students.

An attitude of positive expectations will be shown by the way you present the lecture and the assignments. It is also conveyed by the TAs when they mark papers and talk to students. This attitude needs to be conveyed in all aspects of the course.

Student success can be obtained first by enforcing reasonable prerequisite requirements, second, by having homework problems of graduated difficulty, and third, by providing sufficient help for students who need help. Making the class more cooperative can also help ensure success. Require students to work in groups during class and encourage group work for homework. If this is done, the homework grade should be a modest portion of the course grade. Group work also ensures that there is some opportunity for students to tutor other students.

Show enthusiasm and the joy of learning during lectures. With a little effort thought-provoking questions can be included in the lecture, in group work, and in some of the homework and test problems.

Individualizing the teaching style is difficult in a lecture, but quite a bit can be done by teaching small parts of the course in a form that will appeal to different learning styles. For example, visual and kinesthetic material can be used in addition to the usual auditory presentation. Lectures plus homework can be arranged to encourage students to go through all four steps in Kolb's learning cycle. (See Section 15.4.) Some advance organizers can be used to help global learners (Section 15.3.3).

In addition to satisfying these learning principles, it is important that the students feel that you are accessible for questions and that the grading scheme is fair. Accessibility for questions includes answering questions both in and out of class. Accessibility requires being available both before and after class, and having a reasonable number of office hours or, even better, an open-door policy (Daly et al., 2012). Since some students are more comfortable talking to TAs, the TAs should also have office hours. Fair tests and grading can be ensured by testing on the objectives (see Section 11.2.1) and by being very careful that grading is uniform. The total course workload should be challenging but not outrageous.

If your class includes all these aspects, it will be a good class even if you are not the most polished lecturer in the world.

6.10. CHAPTER COMMENTS

We have devoted more attention and space to lecturing than to any other teaching method, because lecturing is the most common method in engineering and lecturing is part of many other teaching methods. Most professors use some form of lecturing, so we wanted to do everything we could to ensure that lecturing is well done and satisfies learning principles. Lecturing is both the best and the worst teaching method imaginable—it all depends on the skill of the professor. Readers interested in a different view on lecturing will probably find Aarabi (2007) of interest.

HOMEWORK

1. Professor X uses the lecture method. List four problems she should be aware of and briefly discuss solutions which will allow her to satisfy learning principles.
2. Consider one of the best lecturers you've ever had. Describe four qualities that made his or her lectures exceptional.
3. Pick one class period in a specific undergraduate engineering course. Select and organize the content to be covered in this one lecture.
4. Write lecture notes for the lecture in problem 3. Include stage directions and questions for the students.
5. For the lecture in problem 3, consider what methods, including the special lecture methods discussed in Section 6.7, you will use to keep the students active. Explain.

6. Make a list of performance characteristics which you think are desirable in a lecture. Make a list of what you actually do. (It may be necessary to have a few students help with this list.) Develop an action plan to make the two lists approach each other.

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CHAPTER 7

ACTIVE LEARNING

"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.

Table 7-1. Percentages of Faculty from All Four-Year Institutions Who Agreed That They Used a Teaching Method "In All or Most Courses" (De Angelo et al., 2009, p. 10)

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

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.

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, communication, 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

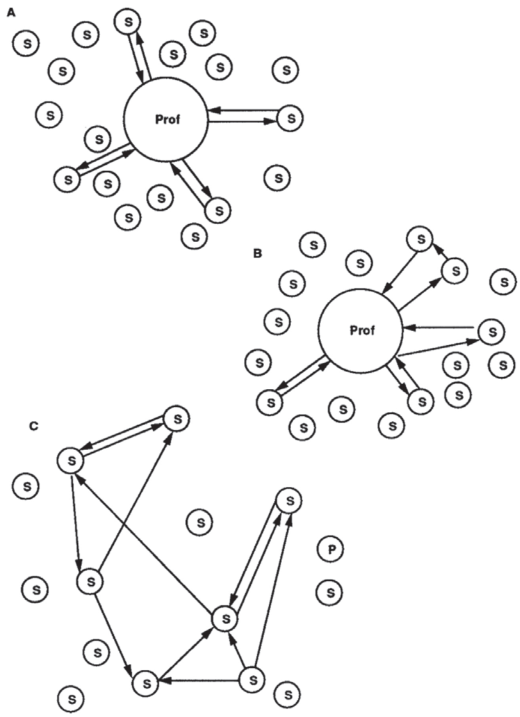

Figure 7-1. Interaction Styles: A. Questions; B. Instructor-Led Discussions; C. Student-Centered Discussions

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 brainstorming (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 deliverable is this list. If the problem is to come up with a consensus about some question, then the deliverable is the consensus. These deliverables should be presented to the entire class. If a reporter has been assigned, that student can make the presentation. Otherwise, let the group choose who will report, or call on a group member at random. Small groups should be told in advance how this reporting will be done. 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 trouble. In the future you can mix the groups up and avoid the exact grouping which caused the trouble. At this time you might want to assign a discussion leader and a recorder to get things started. (One nice thing about informal grouping is that problem groups last for only about 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 competiveness, 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 Unsveld, a mountain climber. "Take care of each other. Share your energies with the group. No one must feel alone, cut off, for that is when you do not make it" (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° 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.

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CHAPTER 8

TEACHING WITH TECHNOLOGY

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

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

Why don't faculty include more technology in their teaching?

1. They do not believe that technology will improve learning.
2. They are unfamiliar with the technology.
3. They do not think they have time to implement technology.
4. They do not believe there are rewards for using instructional technology. Only 20.3% of professors at 4-year institutions agreed that "Faculty members are rewarded for their efforts to use instructional technology" was very descriptive of their institutions (Higher Educ. Research Institute, 2009).
5. They do not have funding for a specific technology such as tablets.

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

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

Note: Responses "don't know" and "not applicable" omitted in analysis.

Hopefully, the combination of chapters 7 and 8 will eliminate the first reason and this chapter will help ease the burden of the second reason.

Delivery media that can replace or supplement live instruction include television, video, streaming video on the Internet, and interactive computer tutorials. These materials may be delivered through a virtual learning environment such as Blackboard or Moodle. We will draw a distinction between live (synchronous) television, which may be delivered on the Internet, and asynchronous delivery by CD, DVD, or downloading from the Internet—all of which will be lumped together as video. Many different teaching *methods* such as lecture, interactive tutoring, discussion, and drill can be used with different delivery media. Television and video are discussed first because these media are often used with the traditional lecture method of Chapter 6. In universities, educational television and video have been used to deliver lectures to remote sites or at different times. Video is also useful as backups for live lectures and for providing feedback to students. A computer can be used as a tool to reduce the repetitive nature of calculations (see Sections 8.3.1 and 8.3.2 on spreadsheets and equation solvers and simulation programs), while most of the teaching uses traditional teaching methods and a live delivery medium. A computer can also replace the traditional live delivery through computer-aided instruction (Section 8.7.3)

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

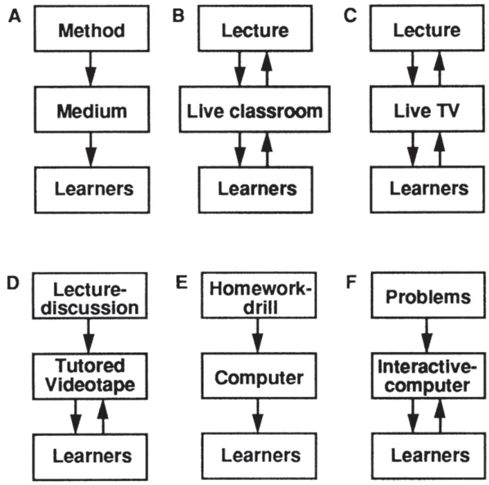

Figure 8-1. Interaction of Teaching Methods and Delivery Medium: A. General Flow Sheet Illustrating One-Way Communication; B. "Normal" Live Lecture (Chapter 6) with Complete Two-Way Communication; C. Live TV (Section 8.2.1) with Complete Two-Way Communication; D. Tutored Video (Section 8.2.2) with Two-Way Communication Between Students and tutor; E. Non-Interactive CAI Drill (8.7.2) with One-Way Communication; and F. Interactive CAI (8.7.2) with Two-Way Communication Between Students and Tutoring Software

Over the years, the introduction of new technology for education has generated initial high excitement followed by disillusionment, although most technologies eventually find a niche in the educational system. Throughout this chapter we will consider what delivery of instruction by technological media can do better than the non-technological delivery alternatives such as lecture, discussion, cooperative groups, and PSI.

Gibbons et al. (1977) present the following list of guidelines for the successful use of technology in education:

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

Of course, this list can be applied to any teaching method if the words "teaching method" replace "technology." If use of the technological medium does not have an advantage as compared to non-technological delivery, the combination of technological delivery medium and teaching method will probably not survive after the innovator has moved on to other activities.

8.1. SUMMARY AND OBJECTIVES

After reading this chapter, you should be able to:

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

8.2. TELEVISION AND VIDEO

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

8.2.1. Instructional Delivery by Television, Video, and MOOCs

What can delivery of instruction by television or video do better than other means of delivering instruction? First, they make it possible to provide instruction at remote sites. This ability has been extensively used for continuing education and graduate programs for engineers employed in industry away from universities. Second, they can be used to break a huge class into much smaller sections. Third, videos provide flexibility in that they can be observed at any time. Fourth, they can be used as "electronic" field trips. Fifth, if some organization will pick up the expenses, the material can be used to deliver a Massively Online, Open Course (MOOC) that is free to the world. Of course, the examinations and credit for the MOOC are not free.

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

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

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

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

Television and video delivery can be an impersonal environment for learning. The term *distance* applies to psychological distance as well as geographic distance. Field-sensitive individuals in particular will have more difficulty adjusting to a television course (See Section 15.3.1). Since the majority of engineers are field-independent, this will be less of a problem in engineering than in other fields. Still, you need to create a sense of contact and to build rapport. Visits to the remote sites during the semester can help tremendously. Professors and/or tutors can also have phone office hours every week, although few students will take advantage of this opportunity. Discussion and questions are more difficult in a live television course even with the students in the studio. Thus, the professor must increase the effort made at soliciting and answering questions. Television encourages student passivity, which is not productive for learning.

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

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

How well do students learn from television or video courses? Based on a variety of studies, the answer is that there are *no significant differences* between student learning as measured by test scores from either television, video or online and from more traditional courses (Bourne et al., 2005; Canelos and Mollo, 1986; Gibbons et al., 1977; Scidmore and Bernstein, 1986). Although some studies have found that on-campus students do better, others have found that off-campus students do as well or slightly better. The net result is that the medium used is not critical. Much more important are the quality of the delivery and the message. At first glance the "no significant differences" result appears to contradict Chapter 7 that shows students learn more with active learning. However, in order to obtain significantly large samples these studies pool a number of classes together. The amount of active learning in each class and in groups watching video together was not controlled for. Thus, there could have been more or less active learning on-campus as off-campus. We would expect, but do not have the data to prove, that students in a class or group watching the video that engaged in significant active learning would learn more than students in a straight lecture course or students watching the video alone.

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

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

Some colleges will accept certain MOOC courses for credit, but doing assessment online is a major challenge to avoid MOOC becoming "Massively Open Online Cheating." How do you really know who is taking the test? Regional testing centers may be used, but security is still a major concern. Although there is a charge for the assessment and for the credit, it is cheaper than tuition. However, for introductory courses typically offered during the first two years of college, such as Calculus I, there already are well-organized, inexpensive ways to earn credit ranging from testing out at the school to taking a CLEP examination (in December 2013 these cost $80 per exam, which is $20 to $26.67 per credit) (College Board, 2013). If the student doesn't need the prestige of an elite university, the MOOC can provide the information needed to pass a credit examination.

Are MOOCs going to change the educational landscape? With the current pass rates, they look like a niche technology useful for mature, strongly motivated students. However, using a MOOC as the pre-class lecture in a flipped class (Section 7.2) has enormous potential and could be the disruptive technology that changes higher education significantly. The resulting blended instruction is discussed in the next section.

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

The other system that has been used extensively for the delivery of classes to remote sites is tutored video instruction (TVI), which is illustrated in Figure 8-1d. Obviously, screencasts (Section 8.2.4) can be used instead of a video—in the remainder of this section "video" will be understood to include screencasts. TVI was originally developed at Stanford University (Gibbons et al., 1977). With this technique a video is produced on campus by essentially the same procedures as live television. It seems to be most effective if the video is made of a live class. The video is then either streamed to a computer or shipped to the remote sites. In any of these formats the students can watch the video at their convenience. When the video is shown at a remote site, a local engineer who is qualified to help teach the material serves as a tutor. The video is shown for roughly five to ten minutes and then halted for questions and discussion. The next segment of the video is then shown followed by a question-and-discussion period. This procedure is repeated until the video is finished. Note that this method includes a significant amount of active learning. The tutor may discuss example problems at any time. If there is a time constraint on class length, the video should be about thirty minutes long so that there is time for the questions and discussion. If the tutor is unable to answer any questions, the professor can be called on the telephone at prearranged times. This is apparently rarely necessary. The professor prepares homework and examinations, sends them to the tutor, and then supervises the grading after the tutor returns them.

This procedure is more flexible than live television and has more live contact except that the contact is with the tutor or instructor instead of with the professor. The Open University in the UK uses essentially this procedure to teach literally thousands of students in a single course (Petre et al., 1998). The Open University is very careful that the lectures are of the highest quality—the production is *not* a professor sitting down at a computer with a camera attached. The tutored groups can then act as a cooperative learning group (see Section 7.3.2) and will have the advantages of cooperative groups. Writing for the New York Times Magazine, Traub (2000) explored the potential for national providers of the video. The 25 most popular US college courses account for 50% of the total credit enrollment. Thus, a small number of academic performers working with a few providers and a large number of instructors who facilitate learning could provide half of the college credit in the US. Note that this procedure is NOT a Massively Online Open Course (MOOC), but a MOOC can serve as the lecture part of the course. It will be more effective than a MOOC because many students need the structure and help provided by the tutors. However, the system is more costly to run than a MOOC, but cheaper than on-campus courses. Instituted on a large scale, it is likely to be a disruptive technology in higher education.

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

1. Practicing engineers at the site.
2. Have a personal interest in reviewing the subject but not be so expert that they will be bored by the video.
3. Have a desire to help teach the course.
4. Be sensitive to the needs of the students and able to draw them into discussion. Tutors with a discussion style are more effective than tutors who want to answer all the students' questions.

Tutored video instruction has also been used to advantage on campus (Gibbons et al., 1977; Scidmore and Bernstein, 1986). TVI allows the school to offer a course even when the professor is not available because of sabbatical or other commitments. Graduate students are happy to serve as tutors and probably find the assignment more enjoyable than being a grader. For on-campus applications of the method Scidmore and Bernstein (1986) found "as much, if not more, success with undergraduate tutors as with graduate student tutors. Undergraduate tutors have frequently just completed the course and are closer to the students' problems than a graduate student." TVI has also been used in undergraduate classes to break supersized classes down into much more manageable sections. With a tutor assigned to each section the students have the benefit of contact and of seeing the professor lecture on the material. Since small classes are always appreciated by students, this application of TVI should receive particularly high student ratings if the class size is kept within the suggested range of three to ten students per section.

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

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

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

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

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

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

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

Will one of these disruptive scenarios occur? Agriculture and industry have both seen the replacement of many workers by technology (Wasfy, Wasfy, Mahfouz, and Peters, 2013). We expect that eventually higher education will also use technology to replace teachers; however, the technology could be different from current technology. Thus, the question is not if this change will occur, but when and how quickly. One of Hennessey's (2012, last slide) closing comments is "Be the disrupter; not the disrupted."

8.2.3. Instructional Hints for Television and Video

As with all techniques and classes, it is the instructor who controls the quality of instruction. Obviously, with television and video there is the added requirement that the production must be well done. However, even great production facilities cannot compensate for poor instruction. The following hints will help ensure a good video:

1. *Be prepared and well organized*. Since television magnifies problems, you must be prepared and organized.
2. *Arrive early at the studio*. Extra time is required for setting up the cameras, and the producer will become very agitated if, as the starting time approaches, the "star" of the show is absent.
3. *If possible use an overhead camera for visuals instead of a blackboard*. It is difficult to obtain in-focus pictures of the entire blackboard.
4. *Make sure the presentation is of high quality*. Material prepared ahead of time must be neat and carefully proofread. If you write notes as the lecture is presented, have the ideas prepared ahead of time. Write few words and few equations. Write neatly. Orient the material horizontally since television uses dimensions with a height of three and a width of four. If large quantities of written material are required, use prepared material which has been handed out to all students in advance. Be sure that the handouts are also of high quality.
5. *Use the principles of good teaching and good lecturing*. Aim for variety in the presentation. A head talking in a monotone is even more boring than a boring presentation in person. Break the lecture into small parts with time for questions, discussion, and group activities.
6. *Work to obtain group participation*. Learn the names of the students both in the studio and at the remote sites. Allow extra time for questions from the remote sites. Repeat all questions since the microphones may not pick up student questions.
7. *Watch the video for feedback*. If necessary, adjust your teaching style. If the video will be reused, edit or reshoot unsatisfactory portions. Prepare a practice video before the semester starts and discuss your performance with a television expert.
8. *In a TVI course, develop written instructions for the tutors for live, in-class activities*. Do not assume that they can develop these by themselves. Encourage the tutors to stop the video frequently for discussion and other activities. Meet with and get to know them since the professors and the tutors form a team. Monitor the tutoring throughout the term.
9. *Have copies of the video and the written materials available online unless they are copyrighted and permission has not been obtained to use them*. Copyrighted materials can be made available at the library or learning center.

8.2.4. Screencasts and Video as Information Resources

Video and screencasts can provide information to prepare students for lab or a flipped (blended) class (see Section 7.2), or as a supplement while working on assignments. Although they obviously overlap with distance education applications, in this section we address screencasts and videos made by the professor without the services of a professional studio. Obviously, a professional studio could also be used.

Videos of lectures made in class one semester can be used the next semester to prepare students for class sessions devoted to problem solving, creative design, debates and other activities. The videos need some editing to shorten them and to remove items that are not pertinent for the current semester. Major advantages of videos and screencasts are that students can watch them on their own time and they can watch confusing parts multiple times.

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

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

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

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

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

8.2.5. Video Feedback for Students' Oral Presentations

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

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

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

No one likes the sound of their voice on video, and many people do not like the way they appear on camera. Since the student is likely to be embarrassed, show the video privately (COSEPUP, 1997). Most students will be very severe critics of their presentation when they see the video. If a student becomes upset while watching the video, be sure to give some positive feedback and point out what worked. The camera is very blunt in showing problems, and usually there is no need to point out what is obvious to the student. Give the student a few pointers on what to do to improve, but do not overload him or her with too much advice. However, after more than thirty years of recording student presentations, both undergraduate and graduate, the more common response we have seen is a positive one. Students discover that all the nervousness they feel while speaking does not show up; it's all internal—their knocking knees aren't visible for all to see. Also, they generally concede that the talk went better than they thought it would, or that they didn't sound as bad as feared. For every student appalled at seeing himself or herself, many more enjoy watching themselves.

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

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

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

8.3. COMPUTERS IN ENGINEERING EDUCATION

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

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

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

1. *Accessibility*. Both the hardware and the software must be readily accessible to both students and faculty.
2. *High-quality software*. The software must do something that the students want it to do, it must have clear and unambiguous screen displays, the interaction between user and machine must be easy, the software must be easy to use, the software must be relatively fast, and above all, the software must be robust.
3. *Faculty interest*. The faculty must have sufficient interest and energy to follow through with the project. The amount of interest and energy required depends on the project. For adopting generic tools such as spreadsheets, the amount is modest, but for writing computer-aided instruction packages it can be staggering.
4. *Advantage*. A computer must be able to do something better than the student can do it working without the computer. If there is no perceived advantage, then students will not use the computer and the faculty will drop the experiment.
5. *Student computer background*. Students must be taught how to use both the hardware and the particular software. If this has not been done in a prerequisite course, then they must be taught in the current course. Particularly for weaker students, learning about unfamiliar hardware and software in a discipline-oriented course can lead to cognitive overload and poorer performance (Whitney and Urquhart, 1990).

8.4. COMPUTER CALCULATION TOOLS

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

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

As long as a spreadsheet has appropriate graphing and scientific function features and is fast enough, the choice of spreadsheet is almost immaterial; however, Excel® is certainly most common. In addition, students who learn how to use one type of spreadsheet can easily learn to use a different spreadsheet on their own. Thus, there is no need to worry about them seeing a different spreadsheet when they graduate. Applications of spreadsheets in engineering courses have exploded and they have been used in all engineering disciplines. Chapra and Canale (1988) show how spreadsheets can be used to implement a variety of numerical methods. Jordan (2012) wrote an Excel® manual that is useful for both professors and students.

The advantages of spreadsheets are discussed by Jordan (2012) and many others. Spreadsheets are easy to learn; one two-hour laboratory is sufficient to learn the basics. Spreadsheets remove much of the tedium from doing calculations and allow the professor to assign more meaningful problems. "What if?" computational experiments are easy, and students can explore the effect of changing parameters, thereby gaining a feel for the magnitudes of parameters in problems. And in certain circumstances they can see what effects can be ignored. Spreadsheets are also easily adapted to discovery learning methods. Instead of being told, students can discover the effect of variable changes for themselves.

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

Students invariably prefer spreadsheets to programming. In addition, it doesn't appear to make any difference if they learn programming or spreadsheets first (Genalo and Dewey, 1988). Students are also able to generalize the use of spreadsheets to other classes and will use them in follow-up courses. In many engineering classes spreadsheets allow students to get to real engineering problems faster, and permit them to focus on thinking since the program does the routine calculations. Since spreadsheets are also extensively used in industry, their use is also realistic. We are strongly in favor of integrating spreadsheets into the engineering curriculum at all levels.

Spreadsheets, however, are slow, large-scale branching is difficult, and it is difficult to use variable names. If students are unfamiliar with spreadsheets or do not use them for a significant period of time, their introduction along with engineering material may decrease the learning of material. This could well be due to oversaturation with new material. If spreadsheets are introduced early and used throughout the course, this should not be a problem. For very large problems the use of spreadsheets becomes cumbersome if not impossible. For these problems discipline-specific programs are often preferable. For the solution of large systems of equations and for many numerical methods, equation-solving software is preferable.

Much of what has been said about spreadsheets also applies to equation-solving programs such as Mathematica, MathCAD, MATLAB, and TK!solver. With an equation solver the user lists equations and the program automatically generates a list of variables. The user gives values for the known variables and asks for a solution. The program then finds a direct solution or iterates to find a solution after the user supplies initial values. Equation solvers perform the input and output routines for the user, including graphing routines, and they choose the algorithm, although the user may be able to override this choice. They are quicker to set up than programming. The user can do "what if?" calculations and can thus learn by discovery. The programs can be used for optimization by trial and error and thus are useful for design problems. The simple features of an equation solver can be learned in one or two laboratory sessions, but some of the more advanced features take considerably more time before the user becomes proficient.

The programs require that students know how to write the equations. However, they do not need to know how to solve the equations, and in the worst case the program can become a black box. Generally, the programs have little logic capability and cannot do branching. Each program has limitations. Unfortunately, equation-solving programs do not appear to be as generic as spreadsheets, and experience with one program does not necessarily translate to facility with another.

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

8.5. SIMULATIONS AND GAMES

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

In our opinion commercial application software such as ADAMS, ASPEN, NASTRAN, SPICE and pSPICE, and specialized simulation programs must be used in engineering education because practicing engineers use simulations. We classify a simulation program as a computer tool if the program is written for general use. If it is explicitly written for instruction, we classify it as computer-aided instruction (CAI). Programs originally written for research purposes are also used in engineering courses (Magana et al., 2012). In engineering, the advantage of commercial simulation programs is that they have a potentially broader market, and more money will probably be spent on their development. In addition, these programs are clearly realistic since they are used by practicing engineers.

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

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

Specialized simulation programs written for a particular problem can be very useful since they allow students to "experiment" with otherwise inaccessible equipment (Squires et al., 1991) or to gain experience which would not normally be available until they are employed in industry (Kabel and Dwyer, 1989). Real effects such as measurement errors and stiction can be programmed into simulations (Goodwin et al., 2011), but these "virtual laboratories" should not be confused with in-person or remote labs that use real equipment. The virtual labs should only be used as a supplement. Unfortunately, the commitment in time and money needed to produce large simulation programs robust enough for student use is huge. Unless significant amounts of grant money are available, the programs would have to be sold to recover the development costs. However, there are still barriers such as equipment incompatibility, a "not invented here" syndrome, and the lack of proven markets which make program development difficult. Intelligent tutorial systems (ITS, Section 8.7), which also require extensive development, have developed a market. The ITS systems had significant grant funding for early development and focused on courses with very large enrollment.

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

Educational games are a form of simulation except games have a goal which is usually to obtain the highest score or beat an opponent. Video games can satisfy many of the requirements necessary for learning such as increased time on task and can result in more learning than occurs in lectures; however, these results are not automatic (Mayo, 2007; Whitton, 2010; Whitton and Moseley, 2012). Games are "active learning environments, which have the potential to teach higher level skills such as analysis, application and evaluation" (Whitton, 2009, p. 3).

Educational games are designed to be constructivist—that is, players learn by doing and constructing their own knowledge structure (see Section 15.2). To be useful in higher education, educational games will have to overcome a certain amount of initial negative reactions. Assessment and proof of learning of higher order skills will be required for acceptance of educational games. In addition, the following items are important in adopting an educational game (Whitton, 2010; Whitton and Moseley, 2012):

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

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

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

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

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

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

8.6. YOUTUBE AND WIKIS

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

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

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

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

A third use of YouTube videos is to have student groups produce their own video as a course project. Examples of chemical reaction YouTube videos from the University of

Alabama and the University of Michigan are available at http://www.umich.edu/~essen/html/344/youtubevids.html.

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

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

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

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

8.7. COMPUTER-AIDED INSTRUCTION AND INTELLIGENT TUTORIAL SYSTEMS

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

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

The disadvantages of drill and practice are similar to the disadvantages of other CAI modes. The student must get past the barrier of using a computer, which for weaker students may be a major impediment. With the advent of extremely portable machines, the requirement that a computer with the software installed had to be available is much less of a problem than it used to be. Finally, developing good programs (discussed in detail later) is a major task.

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

The third mode listed by Simons (1989) is simulation (discussed in Section 8.5). A CAI simulation program is more likely than a general simulation package to consider decision making explicitly and to have feedback if the student has difficulties. The simulation should have many options and decisions for the student so that he or she can practice the functions of an engineer.

Does CAI work? Yes, but only if the students use the programs. Students often refuse to use CAI programs (Roskowski et al, 2002). Of course, this is not unique to computers. Some students refuse to read a textbook or attend a lecture, but the problem does appear to be worse with computers.

Do students who use CAI learn better than by traditional methods? It depends on the program. Many instances of improvement are reported (Graesser et al., 2005; Kadiyala and Crynes, 2000; Turner, 1988), but there have also been reports of no improvement when compared to traditional methods (Turner, 1988). If a computer program is simplistic and just does what a textbook can do (e.g., Figure 8-1e), then there is no gain in using CAI. If the computer makes a diagnosis of where the student's difficulties lie and refers the student immediately to text that includes the appropriate information, improvement is observed.

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

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

One major difficulty with CAI and ITS is the amount of time required to author a CAI or ITS program. Trollip (1987/88) states, pessimistically, "Whether or not assistance is sought, it comes as a nasty surprise to most who start in the field of instructional computing just how difficult it is to produce useful, good material, and how long it takes to do it." Most engineering professors do not have all the skills necessary to develop CAI programs, and a team must be assembled. Nelson et al. (1985) organized a twelve-member team to write CAI for a one-semester statics course, a multiyear project. This CAI was intended to support an existing textbook, and only twenty-five hours of CAI were prepared. Much of the effort was expended to be sure that the CAI programs would give the user as much control as he or she normally has with a textbook! Of course, when completed, the CAI program will have the advantage of interaction and immediate diagnostic feedback. The use of new authoring languages (e.g., the Cognitive Tutor Authoring Tools developed by PACT, http://ctat.pact.cs.cmu.edu/) can reduce the effort, but writing a CAI program remains a formidable undertaking.

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

The same arguments apply to CAI and ITS software, and the marketing and sales system is still being developed for courseware; however, see the Carnegie Learning (2013) advertising. There are several additional obstacles to the wide distribution of CAI and ITS courseware:

1. *Computer incompatibility*. With every change in hardware or operating system, software needs to be updated. This is difficult when the market is small.
2. *Professorial indifference or in some cases hostility to CAI and ITS*. Even if a professor wants to use CAI or ITS, there is the "not invented here" syndrome.
3. *Cost*. Not only must the very high development cost be recovered, but this has to be done from a smaller base than for a textbook. In addition, students will revolt if they have to pay for both a textbook and CAI or ITS software.
4. *Rewards*. Many universities give little if any credit toward promotion and tenure for the development of instructional software (Trollip, 1987/88).
5. *Identification with television*. CAI is often identified with television and may be seen to encourage students to abandon books and traditional scholastic values (O'Neal and Vasu, 1991). This can feed professorial hostility.

Because of these problems and with current high development costs, we think that the outlook for CAI and ITS is limited to large enrollment courses. In engineering large enrollment classes include calculus, chemistry, physics, computer programming, and certain lower-division engineering classes. The engineering classes with large enrollments include circuits, thermodynamics, statics, dynamics, and fluids. On the other hand, Wasfy et al. (2013) argue that ITS, perhaps in combination with MOOCs, will become a disruptive technology that will increase student learning with significantly lower costs resulting in widespread loss of teaching positions.

8.8. CHAPTER COMMENTS

It is extremely difficult to give the flavor of teaching with a technology in a book using print as the medium. If you are interested in any of these techniques, obtain samples and be a student for an hour or two using the sample to learn a topic. These demonstrations will give you a feel for whether you want to proceed in exploring use of the technology. The predictions (see the last paragraphs in Sections 8.2.2 and 8.7) that a disruptive technology will drastically affect higher education should be a strong motivator to pay attention to these methods.

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

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

HOMEWORK

1. Pick one of the teaching methods listed in the first objective of Section 8.1. Visit a facility or web page where this technique is in use and act as a student for one class period to experience the method.
2. For the teaching method chosen for problem 1, outline in detail how the method could be used either to teach or to supplement a specific engineering course.
3. Outline how you would use generic software in a specific engineering course. If appropriate, consider how the students would learn to use the software.
4. One of the arguments against extensive use of simulations in engineering education is that students will use the software as a black box and will not look at the output critically. Explain this argument. Develop methods to prevent this from being a major problem.

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CHAPTER 9

DESIGN AND LABORATORY

"Engineering without labs [and design] is a different discipline. If we cut out labs [and design] we might as well rename our degrees Applied Mathematics" (Eastlake, 1986).

There is nothing wrong with a degree in applied mathematics, but that is not the degree that students and companies think they are getting. Design and laboratory classes are also important in accreditation (see Section 4.7), in the ASEE Quality in Engineering Education Project (ASEE, 1986), and in the Carnegie Foundation book on revitalizing engineering education (Sheppard et al., 2009). Despite almost general agreement on the importance of design and laboratory work, there has been a tendency in the past to cut these programs since they are expensive, messy, hard to teach, time-consuming, and not obviously connected to the university's other mission—research.

We cannot delve into the technical details that become important in teaching design and laboratory courses, so the discussion will necessarily be more abstract. We will consider the purposes of design and laboratory work and then consider methods for teaching these courses.

9.1. SUMMARY AND OBJECTIVES

After reading this chapter, you should be able to:

- Discuss what design and laboratory work add to the education of engineers. Discuss the problems inherent in teaching design and laboratory courses.
- Develop a plan to incorporate design throughout the undergraduate engineering curriculum.
- Compare and contrast the different ways to teach design. Highlight the advantages and disadvantages of each method.
- Describe how you would select groups for a design project or laboratory experiment. Justify your method.
- Explain the appropriate laboratory structure for students at different levels.

9.2. DESIGN

There is good news about engineering design education. There is an increasing emphasis on design in engineering education (Dym et al., 2005; Froyd et al., 2013). Major design experiences (often called capstone design) have long been required by ABET. Capstone design courses were developed "in an effort to bring the practical side of engineering design back into the engineering curriculum" (Dutson et al., 1997). There is also a resurgence in first year or "cornerstone" engineering design courses (Dym et al., 2005; Froyd et al., 2013). First year design courses increase student development on the Perry scale (see Chapter 14) (Marra et al., 2000) and they increase retention of first year students (Knight et al., 2007). Although Rowan University has shown that engineering curricula can include design in all four years (Newell et al., 1999), at most schools, with the exception of computer engineering programs, the middle two years are barren of design. The Carnegie plan for reorganizing engineering education would include design in these years (Sheppard et al., 2009).

Many engineers contend that designing is the heart of engineering. All the mathematics, physics, chemistry, and engineering science courses are background for what makes engineering different from applied mathematics or the physical sciences. Yet, there is no universally accepted working definition of what design is. Prior to ECC-ABET-2000, ABET required one-half year of design in engineering curricula and listed the following activities and processes that might be included (ABET, 1989). Design:

- Produces a system, component, or process to meet a specific need.
- Is an iterative process that utilizes decision making with economics and employs mathematical, scientific, and engineering principles.
- Includes some of the following: setting objectives, analysis, synthesis, evaluation, construction, testing, and communication of results.
- Has student problems that are often open-ended, require use of design methodology and creative problem solving, require formulation of the problem statement and an economic comparison of alternate solutions, and may require detailed system details.

Programs would dutifully list the appropriate number of credits as design, but since many of the credits listed as design barely qualified, there was a continual struggle to be sure that sufficient design was included in the curriculum (Jones, 1991). An inadequate design curriculum was often noted as a deficiency during ABET visits.

Current ECC-ABET-2000 requirements for design (ABET 2013) are included in criteria 3c and 5. Criterion 3c lists the design outcome:

> "an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability"

Criterion 5 is concerned with curriculum. It states the curriculum will contain

> "(b) one and one-half years of engineering topics, consisting of engineering sciences and engineering design appropriate to the student's field of study. The engineering sciences have their roots in mathematics and basic sciences but carry knowledge further toward creative application. These studies provide a bridge between mathematics and basic sciences on the

> one hand and engineering practice on the other. Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs."

Criterion 5 continues with the statement,

> "Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints."

We will first discuss appropriate goals for the design part of courses and then explore methods for teaching design and including design throughout the curriculum. Finally, we will examine four different methods for teaching design—design projects, case studies, guided design, and design clinics. What we will not attempt to do is to list activities or projects that are appropriate for teaching design in different areas of engineering.

9.2.1. Design Goals

Based on the ABET description of design a wide variety of possible goals for the design part of a course can be generated:

Problem definition and redefinition. Students will be able to define and redefine problem statements as they work their way iteratively through open-ended problems.

Synthesis and creativity. Students will be able to synthesize new designs using the principles of creative problem solving (see Section 5.7).

Troubleshooting. Students will be able to take an existing design that does not work up to specifications and make it work. Since troubleshooting is quite different than designing a new device or process, students need a chance to practice (Woods, 1980).

Use of engineering, mathematics, and science principles. Students will be able to integrate a variety of engineering, mathematics, and scientific principles into the solution of design problems.

Computer tools. Students will use computer tools such as spreadsheets, general mathematical packages, and engineering discipline-specific simulation packages to do detailed routine calculations. "A course which does not use professional software is preparing our students for a type of work which does not exist anymore" (Paris, 1991).

Decision making. Engineers must be willing to take the responsibility of making decisions knowing that something could go wrong since perfection can never be attained (Florman, 1987).

Economic evaluation. Students will evaluate solutions based on economic and other criteria to determine the best solution among several alternatives.

Completion of a deliverable. It may be possible to have students carry out all steps of a design including the construction and testing of a deliverable. When this is possible, it is extremely motivating for them to see their design built and used.

Industrial or real-life experience. Design projects are normally much more realistic than engineering science problems which are concocted to illustrate a single principle. An additional goal may be to have students solve actual industrial problems.

Oral and written communication. Students are expected to develop professional skills to communicate their results.

Planning and managerial skills. Students can learn how to plan effectively and direct fairly complicated projects.

Interpersonal skills. While working in groups students can learn interpersonal skills, become adept at teamwork, and start developing leadership skills. Teamwork has become increasingly important as technology becomes more complex (Florman, 1987).

Globalization. Engineering design has become globalized, and students in global teams produce better documentation of their projects (Dym et al., 2005) and are probably better prepared for industry.

Confidence. Students can develop confidence in their ability to function as engineers.

This is a long but certainly not all-inclusive list. Dekker (1989), Dym et al. (2005), Feisel and Rosa (2005), and Harrisberger (1986) discuss other possible goals. No single course can satisfy all these goals, although some professors make a valiant effort. However, an entire curriculum can be designed so that these and other objectives are satisfied. The professor's task is to select appropriate goals for the design portion of a course. These goals must be appropriate for the student level and the time allotted to design. For example, completely open-ended, unstructured problems with no guidance are not suitable for first-year students but may be very appropriate for seniors. Once the goals have been determined, teaching methods can be selected (see Sections 9.2.2 through 9.2.7).

9.2.2. Teaching Design

The old ABET literature (e.g., ABET, 1989) explicitly states that material in engineering courses can be split between engineering design and engineering science. A strict dichotomy between engineering science and engineering design is a false one. The engineering design experience should be developed and integrated throughout the curriculum. Sheppard et al. (2009) propose using design and laboratory throughout the curriculum as a means of teaching students the professional aspects of engineering. The new ABET requirements (ABET 2013 and Section 4.7) require a meaningful, major engineering design experience.

Spreading design throughout the curriculum allows the faculty to develop a design experience where students start working open-ended problems as freshmen or sophomores. These first projects are presented with a significant amount of guidance using a procedure such as guided design (see Section 9.2.5). Procedures for teaching freshmen design are discussed by Marra et al. (2000), and Dym et al. (2005). The best methods such as the Integrated Teaching and Learning Program and Laboratory (ITL) at the University of Colorado-Boulder use hands-on projects (Knight et al., 2007). The prime movers in creating the ITL and courses it supports, Jacquelyn F. Sullivan and Lawrence E. Carlson, were recognized for their contributions to engineering education with the 2008 NAE Bernard M. Gordon Prize.

Ideally, design ideas would be included in traditionally non-design classes in both the second and third years, or design studios can be continued during these years (Newell et al., 1999). Unfortunately, the sophomore and junior years are often devoid of design. The Carnegie Foundation study recommended greatly increasing the amount of design in these two years (Sheppard et al., 2009). The first year design courses and the traditional senior design classes and design laboratories would be retained. However, students would be better prepared for senior design, and professors would see fewer students who are totally unprepared for open-ended design problems.

Introducing some ideas of engineering economics into the curriculum during the first or second year allows a professor to include relatively simple design problems and economic optimizations that can only be talked about instead of being done if the students have not studied economics (Sullivan and Thuesen, 1991). Talking about something is a totally ineffective teaching method; students must do what they are to learn (Sheppard et al., 2009, Chapter 21). In our experience, students find some of the economics (costs, cost indices, payout periods) easy, while other parts (such as discounted cash flow) are more challenging. It helps if the textbook talks about economic factors, but unfortunately many engineering textbooks are written in an economic vacuum. Since students see the design problems with economics as real engineering, these problems are motivating as long as the professor does not overburden the problem with detailed calculations. Computer tools such as spreadsheets, mathematical packages, and simulation programs are appropriate here to remove the burden of routine calculations.

How do you add design focused problems to an already overloaded curriculum and overloaded courses? In some courses substitution of open ended design problems for some of the single answer problems used currently will be straightforward. In other courses it will be necessary to reduce the coverage in lectures and expect students to learn some of the material on their own. If the design problem includes this material, students will learn it, and they will learn how to learn on their own. You can help by having clear objectives, making sure resource material is readily available, and believing that students can master the material on their own. The design problem can be included as a small project, a case study, or as a guided design project.

Another aspect of design is the use of off-the-shelf components. Standard components can easily be introduced into straight-forward design problems in sophomore and junior courses. For example, in a course on fluids or hydraulics students can be required to learn on their own about components such as valves, pumps, pipe joints, and pipe supports. The Visual Encyclopedia of Chemical Engineering Equipment (Montgomery, n.d.) is a good source for equipment of interest to all engineering disciplines.

An important part of design is creativity and synthesis. Since most traditional curricula cover only application and analysis during the first three years, it should be no surprise that many students have difficulty with creativity and synthesis in senior design. Including creative exercises and synthesis problems throughout the undergraduate program should make most students more creative designers. The methods for teaching problem solving and for fostering creativity discussed in Chapter 5 are appropriate for the design component of classes if they are integrated with the class content.

There are many significant difficulties in teaching design at any level. The first difficulty is the development of good design projects. Every engineering professor has one or two good design projects stored in her or his head. Design projects can be recycled and reused by giving the students electronic files of all the reports and telling the students to improve on the designs. However, this cannot be repeated too many times. New projects are needed probably every two or three years. Thus, the first cycle is not the problem; it is the second, third, and following cycles. There are sources of problems that can be tapped by professors but are unlikely to be tapped by students. Published case studies (see Section 9.2.5) and professional society design contest problems such as the American Institute of Chemical Engineers Contest Problem are useful. Industrial interaction can produce interesting problems with the added benefit that the problems are "real" (Emanuel and Worthington, 1987). Ring (1982) suggests that cities can be used as a source of problems. Other rich sources of projects are designs for people with disabilities (Hudson and Hudson, 1991), local non-profit organizations, non-governmental organizations (NGOs), and hands-on museums. Finally, we suggest that professors from different institutions collaborate on developing design problems. Each year a professor from a different school could develop a problem and all the schools would use the problem and grade their own students. The labor of preparing new problems could thus be reduced significantly. In addition, student teams constituted from a number of schools would help prepare students for the globally networked teams common in industry.

9.2.3. Team Selection and Grading

Since design problems are usually team efforts in industry, it is appropriate that they be team efforts in school. Some professors allow students to pick their own teams. This does not follow industrial practice and tends to result in teams that are very uneven in ability. Emanuel and Worthington (1987) suggest that professors assign groups with the following selection criteria:

- Mix leaders and followers within a team.
- Distribute abilities and experience among teams.
- Place one person with initiative on each team.
- Mix foreign students among teams to force communication in English.
- Do not put roommates on the same team.
- Mix men and women in teams; however, in lower level courses women and underrepresented minorities should be put in teams in pairs.
- Use teams with three members.
- Be sure at least one team member lives close to the campus as this facilitates copying, computer use, and so forth.
- If travel to a company is required, be sure at least one student in each group has a car.

We would add to this list:

- Mix students with industrial experience such as co-op or internships among teams.
- Mix students with computer skills among teams.

The MBTI (see Chapter 13) has been used for team selection (Emanuel and Worthington, 1989). However, dysfunctional teams can result if team members try to act in accordance with their Myer-Briggs type instead of as is appropriate for the situation (Emanuel and Worthington, 1989). After trying different selection procedures, Emanuel and Worthington (1989) stopped using the MBTI for selection but instead used it to help the groups function better during the semester.

Groups malfunction for a variety of reasons. Perhaps the most common problem arises when one student does not do a fair share of the work. If the class is to be a learning experience in teamwork, you should not ignore these problems. The MBTI can be used as a diagnostic tool to help explain the problems; however, do not allow students to use their type as an excuse. Instead, tell students that the types show weaknesses that they must work on. Even without the MBTI you should encourage students to discuss group problems and then meet with the group to try to find resolutions. Design groups can be considered as a type of cooperative group, and many of the comments in Section 7.4.2 are appropriate for instruction and management of these groups.

Grading of groups can also be a problem. Since the group is producing a group report, it is appropriate to give the students a group grade. However, students often feel that this is unfair if one student has not done a fair share of the work. This problem can be resolved in several ways. Talk to individual students and then to the group, and if appropriate assign a lower grade to the shirking student. Second, give the students a group grade and have the group assign points to each student. Most groups will assign each student an equal number of points, but groups where one student has obviously shirked responsibility will differentiate. However, Eck and Wilhelm (1979) point out that these groups often engage in significant conflict over grade distribution and that some type of arbitration scheme may be necessary. Third, require every student to turn in an individual progress report every week (Stern, 1989). From these you can usually make a rational decision on how to partition the final grade (and incidentally can usually predict which groups will turn in good reports). Fourth, assign all students the same grade despite the claims of unfairness. Fifth, design a formula for partitioning the grade so that a variety of inputs are included. (Emanuel and Worthington, 1989). Finally, use the online tool CATME (CATME, 2013; Ohland et al., 2006) or other peer evaluation scheme to obtain rich feedback from all the group members.

What about important technical content that was either skipped in prerequisite classes or which students did not learn? A significant portion of many design courses cover economics, but this time should not also be used as a catch-all to reteach other material. Provide the students with resources (perhaps their own textbooks) and have them learn or relearn the material on their own. Engineering students can be surprisingly efficient learners when they see the need to learn material in order to complete a design assignment.

A final significant problem in design classes is time—both student and instructor time. Students need to learn how to develop a work plan and how to schedule a design project. In addition, some help in improving efficiency is appropriate. If design is included throughout the curriculum, then efficiency, time management, and scheduling can be discussed every semester. This repetition is helpful in learning how to apply these ideas. The problem with instructor time is that many universities undervalue design classes and overload professors who are teaching these classes. Design classes are time-consuming because of the need to develop problems, consult with student teams, and grade lengthy reports. Providing sufficient resources for design requires an administrative solution, which should include sufficient rewards for professors teaching these courses (Jones, 1991).

9.2.4. Design Projects

The most common way to teach design is with project-based learning (Dym et al., 2005; Du et al., 2009). Students, usually in groups, are given a design problem and told to do the design. Since engineers learn design by designing, this is certainly an appropriate procedure. In addition, people remember the things that they do. We can remember our senior design (and laboratory) projects after forty-five years, but we don't remember details of any of the lectures. The projects must be open-ended to be considered design. Multiple solutions of a well-defined problem are optimization, not design (Dekker, 1989). The emphasis of project-based learning is on applying and integrating knowledge and skills while problem-based learning (Section 7.5) focuses on learning new knowledge and skills.

The amount of guidance students need depends upon their maturity. Freshmen need significant guidance, and a guided design procedure (see Section 9.2.6) should be considered. Seniors need the opportunity to solve significant design problems with little guidance. It is helpful if students have the opportunity to work up to a totally unguided design project by working on increasingly difficult designs with decreasing guidance during their junior year and first semester of senior year. Design projects can be classified in many ways. Dekker (1989) suggests classifying them on the basis of various dichotomies.

- Fun versus serious
- Academic versus real world
- Paper versus hardware
- Creative versus structured
- Individual versus group
- Disciplinary versus interdisciplinary
- Small versus large

Fun projects can include brainstorming a float design for a parade, creating a "Rube Goldberg" design, and so forth. Hardware projects, which mix design and laboratory skills, can be extremely motivating, because students can see what they have designed. Dekker (1989) suggests that designing will be creative if students design something that is unknown. For example, have them design a "dollar bill picker-upper" or a unique machine that will only be used to make advertisements interesting to sell a common household item. Creative designs can be encouraged by showing students one design for accomplishing a task and then asking them to develop a competing design. This can be made more realistic by giving them the patent and telling them to develop a design that does not infringe on the patent. This procedure also brings up the subject of patents and patent law in a meaningful way.

Since many companies use interdisciplinary design teams, an interdisciplinary project is a useful experience, and ABET requires the ability to work in multidisciplinary teams. With advances in globalization international teams are also of interest and would certainly help students satisfy ABET criterion 3h. The technical performance of global teams competing in the Lincoln Arc Welding Design Competition was equivalent to US teams, and their documentation was better (Dym et al., 2005). A series of small projects allows for variety, different leaders, multiple grading opportunities, and a gradation in the degree of guidance. Large projects allow for more realistic problems, can be more open-ended, and require much more detailed planning and scheduling. It is useful if students see some of each of these different types of projects during their period in school.

It is obviously desirable to use projects that are real and have input from practicing engineers from industry or government. A variety of ways of obtaining this input are discussed by Harrisberger (1986), among others. Setting up the appropriate industrial or government contacts can be very time-consuming. Once the contacts have been made, you need to arrange for sponsors. Companies are much more serious about design projects if they pay for the direct costs (not including labor) of the projects. Requiring payment helps to ensure their continued interest. Projects must be screened since some may be too easy or too difficult for the time allotted. A company engineer needs to be involved in the evaluation of projects, but if many different companies are sponsoring projects, you need to control grades to ensure uniformity in grading. Other additional problems include the need for student travel to and from the client and the occasional lack of cooperation when a company refuses to release necessary information.

Balancing the difficulties in working with companies on design projects are the benefits. The opportunity to work with practicing engineers can give students contacts for future jobs and references. There is no question in their minds that the project is real and relevant. Students are often surprised by the messiness of real problems and the difficulty of relating them to the mathematically tractable problems solved in class. Professionalism is obviously important, and students are more likely to behave as professionals. Finally, successful performance can give students the confidence that they can be successful engineers and can on occasion result in a job offer.

A different type of hands-on design project is *reverse engineering* and *redesign* (Ingle, 1994; Wood et al., 2001). Students take apart an object such as a toaster or a bicycle to determine how and, if possible, why it was designed in a particular way. Students are required to keep careful records of each disassembly step. To ensure that the students are careful and record not only where all parts go but also their configuration, they should be required to reassemble and test the device when finished. The student groups are then asked to redesign the object to improve it in some way. Since redesign should also include design that does not infringe on any patents, this step is a natural point to bring in a discussion of the US patent system (Garris, 2001). In engineering disciplines such as chemical engineering, industrial engineering, and nuclear engineering where processes are designed, reverse engineering can be done by dissecting a detailed flow sheet piece-by-piece.

Regardless of the type of project, both oral and written reports should be required to stress communication. Weekly progress reports are useful to help prevent procrastination and to pinpoint problem groups. If a company is sponsoring the project, a presentation to the company is in order, but only after a full-scale dress rehearsal in front of the faculty.

9.2.5. Case Studies

A case study is a detailed description of how a professional approaches a problem. A number of engineering case studies are listed as available on the web for purchase or subscription (do a Google search). The American Society of Civil Engineers (ASCE) is particularly active in the development of case studies. In addition, many descriptions of solving tough engineering problems are available in books (e.g., Bosela et al., 2013; Herring, 1989) and in the trade literature. Patents can also serve as case studies (Garris, 2001). Videos are available for a number of chemical industry accidents http://www.csb.gov/videos/, and case studies could be built around these videos. Section 4.8 presents a case study in curriculum development.

The best cases contain most of the following (Weaver et al., 1994):

1. Use “real” cases based on real data. They have the advantage that the resolution can be explained after the case is finished. Weaver et al. (1994) think fictional cases are OK, but Naumes and Naumes (2000) strongly disagree.
2. Include disinformation (extraneous data) because in real design disinformation is always present.
3. Provide sufficient description of the situation including the characters and dialogue so that students can interpret what the characters are thinking in a variety of ways.

4. Write reasonably complex cases.
5. Include a core of information which can be related to theory, research and knowledge.
6. Develop a primary theme and ancillary issues. Deliberately entangled primary and important tangential issues are realistic.
7. Make the case provocative and important to the students.
8. The presentation should not provide a resolution to the problem.

Case studies can be used in a variety of ways and are useful in both design and non-design classes. Herreid et al. (2012) classify the use of case studies as (a) individual assignments, (b) lecture format, (c) discussion format, and (d) small group format. They argue that the discussion and small group formats are most useful in engaging students. The "Interrupted Case Method" is recommended because it approximates the way much engineering work is accomplished. The students are first given background information and then the case is interrupted while the students study the problem. Next they are given more information and asked to do more work. After the students have finished, the actual final results are presented.

Case studies, particularly of failures, are excellent for satisfaction of the ABET professional outcomes (Delatte et al., 2013). Many case studies consider ethical questions and provide a basis for discussion. They also help to introduce the engineering profession and motivate some students. Case studies are useful in introductory engineering classes to help show students that the material being studied is relevant. Yadav et al. (2010) compared student test scores in a mechanical engineering introduction-to-modeling course for students in a section taught by the case study method to students in a lecture section. The method of instruction produced no significant difference in the students' test scores; however, students in the case study section thought that this form of instruction was beneficial in learning the material and that they were more engaged than in lecture courses.

Case studies can be used in design classes, although they are not a substitute for project work since they are less open-ended (students will consider the case study the solution). Instead, case studies should complement projects. They are particularly useful in showing the human aspect of engineering. And they can show the importance of non-technological factors, such as marketing, in the success of products. Instructors can also obtain project ideas, data, a scenario, and so forth, from a case study.

Case studies are extensively used in law and business schools. Myers (1991) discusses the history of case studies and provides references for applications outside engineering. He notes that Harvard Business School introduced a seminar for professors to teach them to teach with case studies. Naumes and Naumes (2000), writing from a business background, discuss the exhaustive process of developing, writing, and testing a case study.

Instead of writing a case study and giving it to students, professors can have student teams develop case studies as a course project. The teams would need to be given examples of good case studies to use as models.

9.2.6. Guided Design

Guided design is a structured way of having students work through case studies step by step and provide feedback after each step. This procedure is particularly appropriate for introducing students to open-ended design problems since there is considerable guidance and feedback throughout. Guided design was developed by Charles Wales and his coworkers (e.g., Heywood, 2005; Stager and Wales, 1972; Wales et al., 1974a, 1974b; Wales and Nardi, 1982). Guided design was first developed for engineering classes and has since spread to a variety of other disciplines.

The guided design procedure is well summarized by Wales and Nardi (1982). The professor uses printed handouts to guide teams of five to six students through an open-ended problem in "slow motion." After the groups are formed, the guided design procedure starts with a printed handout which explains the problem situation and the student roles. The student groups then define the problem statement and set goals. This is done by a cooperative group discussion (see Section 7.3). After five to twenty minutes the groups receive a printed sheet which tells what the professional engineer did. It is important to stress that this feedback sheet does not represent the solution but shows what one professional did. This point can be made quite clearly if some of the feedback sheets contain actions which are not particularly clever or are ethically dubious. The student groups then discuss the printed feedback sheet and compare their responses to that of the professional engineer. Since it is the design process which is being taught and not a particular answer, the professor must be careful in evaluation.

The guided design procedure then advances step by step through a specific problem-solving or design procedure. For example, the problem-solving strategy in Section 5.4 can be used. Wales and Nardi (1982) recommend the following ten steps:

1. Outline situation
2. Define goals
3. Gather information
4. Suggest possible solutions
5. Establish constraints
6. Choose solution path
7. Analyze factors needed for solution
8. Synthesize solution
9. Evaluate solution
10. Make recommendations

When we used guided design, we made step 5 the third step in the process.

For each step the students first complete the step and then receive and discuss the feedback. Guided design projects can take from two hours to several weeks. At the end of the guided design students can be required to communicate their results orally and in writing. While the guided design proceeds in class, the students can be assigned readings and homework for outside class. The groups can be encouraged to meet outside class as cooperative learning groups.

Although guided design was first developed as a procedure where all information transfer was in printed form (books and handouts), it can easily be adapted to the laboratory portion of a lecture class (Eck and Wilhelm, 1979). For students who are unfamiliar with working in cooperative groups, it is useful to use the first laboratory period for exercises in interpersonal communication, such as paraphrasing, self-disclosure, maintenance contributions to the group, and an ethics exercise with student observation (Eck and Wilhelm, 1979). After every group exercise, do some group processing to help students improve their skills.

What do you do in guided design? You must prepare or select the case studies and put them into a guided design format. Some prepared projects are available (Wales et al., 1974;

Eck and Wilhelm, 1979). If a prepared guided design project is not available, then you can convert old design projects, convert case studies, or develop new projects in the guided design format. Potential developers need to be aware that developing a good guided design project from scratch is very time-consuming.

Wales and Nardi (1982) discuss the development of new guided design projects. First the project must be outlined and divided into labeled steps following the problem-solving or design strategy of choice. A story line and realistic roles must be developed for the students. This step is important since it establishes a need for the project and helps to motivate the students, who must be active in each step. Since learning the process is the important goal, students should gather information only once and have an opportunity to practice the decision-making steps. Students should be asked to make important decisions. Asking them to make trivial decisions reduces the credibility of the entire project.

The form of the written feedback is important, as it models what an experienced engineer does to solve the problem. Be sure to write that the engineer would have done the following, not that *you* should have done the following. Since the problems are open-ended, the feedback can serve only as a model of possible actions. The students may tend to resist this at first, so be careful not to reinforce their belief that this is the correct solution. Be sure that the feedback responds to the questions that the students were asked in the instruction.

In a guided design class students must learn the content outside class by reading, discussing in their groups, doing homework, and so forth. In class they learn how to apply this content to open-ended design problems. You need to be sure that the printed learning materials are good. If the textbook is not clear, then additional notes or study guides must be developed. Some class time needs to be available for answering questions, reviewing the homework, making class assignments and so forth.

Once the guided design period starts, you are a guide and coach, not a lecturer. The first challenge is to form groups and to get the groups off to a good start. Group assignments are discussed in Sections 7.4 and 9.2.3. During the project you and the TA can circulate among the groups. If a group is functioning well, just listen and then briefly provide some positive feedback such as, "This is a great discussion. Keep it up." Some groups will need help getting started. Ask questions about the project or about group processing. If necessary, appoint a leader and a recorder. The behavior of students is often markedly more focused if they have an assigned role. To provide proper feedback to the groups, you or a TA should be available for every twenty-five to thirty students.

There are a variety of ways to assign group project grades. One approach is to have the groups assign the grade that they think they have earned. If their grade is higher than what you think they have earned, make them redo their project and their report until they have earned the higher grade (Eck and Wilhelm, 1979). This procedure is most appropriate for long projects.

The results reported for guided design have been impressive (Eck and Wilhelm, 1979; Heywood, 2005; Stager and Wales, 1972; Wales and Nardi, 1982). The instructor spends much more time with the students on high-level cognitive tasks. And they show better retention, higher grades both in the guided design course and in follow-up courses, increased confidence, and greater motivation. The classes show more cooperation and better group dynamics than other design classes. Students rate guided design classes higher than they do other design classes. However, it is not uncommon to have one or two poor groups that do not function well. The members of these groups do not fully benefit from the course.

As noted previously (Sections 7.2 and 7.7.2), engineering education has cycles and fads. Guided design was a minor fad while Charlie Wales, the charismatic developer of the method, disseminated the method at numerous meetings and presentations. The fad has died out and a useful teaching method is currently seldom used.

9.2.7. Design Clinics

Actual practice in engineering is obviously beneficial to students. A design clinic is one way of providing an internship activity. Other approaches to providing industrial experience are industrial cooperative programs and summer internships. The following are advantages of the design clinic approach (Harrisberger, 1986):

- Students have a significant industrial experience.
- Students make contacts with practicing engineers.
- Students become confident and more professional.
- The design clinic can fit into the normal course structure.
- Students need no extra time for graduation.
- The design clinic can be controlled by faculty members.
- The design clinic can be self-supporting.

There are models of the design clinic approach at Harvey Mudd College (Bright and Phillips, 1999), University of Alabama (Harrisberger, 1986), Rowan University (Newell et al., 1999) and the University of Michigan (Michigan Engineering, 2014). Clive L. Dym, M. Mack Gilkeson and J. Richard Phillips, were recognized with the 2012 Bernard M. Gordon Prize for Innovation in Engineering and Technology Education for their development of the Harvey Mudd Design Clinic.

The design clinic assumes that basic technical knowledge has been covered in other courses. In the clinic, students first learn a variety of skills and then apply them in a supervised professional practice working on a real industrial problem. For example, students take a three-credit skills course in the first semester of their senior year, which consists of two seminars and one three-hour lab every week. In the seminars the students have lectures, take diagnostic tests such as the Myers-Briggs Type Indicator, make and critique presentations, listen to panels, and so forth. The content is concerned with the practical aspects of engineering instead of technical content. Thus students learn skills for presentation, listening, writing, record keeping, teamwork, leadership, project planning, creative problem solving, design methodology, retrieving and finding information, persuasion, and assertiveness.

The laboratory portion of the skills course consists of group projects in which students have the opportunity to practice the skills covered in the seminars. The laboratory is also used to introduce them to the solution of open-ended design problems. The projects done in the laboratory consist of an ideation exercise, a management simulation game, an extensive guided design project, and an extensive competitive design study. Note that the class starts with significant guidance in solving open-ended problems and then reduces the amount of structure.

During the second semester students take an internship course. Groups of three work on company-sponsored problems. The companies are expected to pay all direct costs, often on the order of $10,000 per project which includes a clinic fee to cover administrative expenses. The design group visits the company for an initial visit to learn about the problem and for a final written and oral presentation. Other visits may be scheduled if needed. All companies are within a four-hour drive of the campus, and student groups are selected so that at least one member has a car. The companies are expected to provide the necessary information and to have an engineer work with the students as needed.

Every group meets with a faculty coach once a week for twenty to thirty minutes. This coaching helps keep the students from procrastinating and keeps them focused on solving the problem on time. Each group presents a midterm progress report in the clinic. A dress rehearsal is presented in front of a faculty jury before the final presentation to the company. All professors in the department are modestly involved by coaching two design teams, which takes about one hour per week. Administrative details of running a clinic are discussed by Harrisberger (1986).

Although the design clinic idea has not been widely adopted, it does appear to be a cost-effective way of providing an industrial internship for all engineering students. In addition, design clinics do not require that the faculty have extensive industrial design experience to teach design.

9.2.8. Design Competitions

Many competitions, such as robot competitions (Firebaugh, 2008; Hernando, 2011; Miksell et al., 2012), the solar house, solar powered car, unmanned vehicle competitions (Paulik and Krishnan, 2001), Baja SAE, and human powered vehicle challenge (Miksell et al., 2012), are inherently multidisciplinary, fit well into design courses, and are strong motivators of many students (Grose, 2011; Wankat, 2005). Since ABET criterion 3d requires multidisciplinary teamwork, design competitions are a natural fit. Competitions that are not multidisciplinary such as the ASCE concrete canoe competition or programming competitions also make excellent design projects, but criterion 3d needs to be assessed in other courses.

One reason competitions increase student learning is that many students buy into the competition and spend a significant amount of time working on the project. It is not clear if the amount of learning per time spent is higher or lower than in standard classes; however, many of the skills learned are different. In a design and build competition the students gain hands-on, practical experience they often do not obtain anywhere else. Long-term competitions often enhance the confidence of students as they realize they can build something that works as designed (Wankat, 2005).

Competitions are a rich environment for assessing satisfaction of ABET criteria for student outcomes. In addition to ABET design criterion 3c, competitions usually include an experimental component (3b), a knowledge (3a) and problem solving component (3e), and very often use computer design methods (3k). On the professional side in addition to criterion 3d, students invariably must communicate their results (3g). Many competitions will involve the student in the economic or societal context (e.g., solar house) or will involve a design for a developing country—both of which are part of criterion 3h and often include contemporary issues such as energy (3j). The professor in charge of the project could easily bring in criterion 3f—professional and ethical responsibility. That leaves only criterion 3i, life-long learning, that does not occur almost automatically as part of the competition.

What factors lead to the same school winning a contest repeatedly? After studying this question, Wankat (2005) determined that the following factors were important:

1. A dedicated faculty adviser.
2. Close alignment between the curriculum and the contest.
3. Tangible university support including equipment and space.
4. A tradition of winning.
5. Strongly motivated students.

9.3. LABORATORY COURSES

More than any other topic in this book, teaching laboratory courses in engineering is specific to the field of engineering and the type of laboratory. Since we must avoid discipline specificity, this section is an abstract discussion of the most concrete part of engineering education—the laboratory.

In contrast to the fairly extensive discussion of design ABET has little to say about laboratory (ABET, 2013). Outcome 3b is "an ability to design and conduct experiments, as well as to analyze and interpret data."

Criterion 7 on facilities lumps laboratory facilities with other facilities:

> "Classrooms, offices, laboratories, and associated equipment must be adequate to support attainment of the student outcomes and to provide an atmosphere conducive to learning. Modern tools, equipment, computing resources, and laboratories appropriate to the program must be available, accessible, and systematically maintained and upgraded to enable students to attain the student outcomes and to support program needs. Students must be provided appropriate guidance regarding the use of the tools, equipment, computing resources, and laboratories available to the program."

Laboratory has become the underdeveloped stepchild of engineering education. ABET has not paid much attention to labs, schools tend to minimize lab work because labs are expensive and consume space, faculty often avoid teaching lab courses because they are time consuming and the teachers are not rewarded for their efforts with high student evaluations, and most students prefer other courses.

9.3.1. Purposes of Laboratory Courses

Laboratory courses can have a variety of different purposes, many of which are explored by ASEE (1986), Eastlake (1986), Fiesel and Rosa (2005), and Sheppard et al. (2009). Since the laboratory and the course structure depend upon the purposes of the laboratory course, these objectives should be decided upon first. No laboratory can be optimal for all purposes. The goals for the course can include:

Experimental skills. Students can learn a variety of skills involved in doing experimental engineering work. These can include certain psychomotor skills, planning an experiment, recording, analyzing and interpreting data, and using modern measuring instruments.

Real world. Students can learn to function in a real-world environment where the theory may or may not work and the equipment occasionally malfunctions. They can learn to distinguish reality from theory. They can also experience working in a climate of uncertainty and can learn the manifold meanings of Murphy's law. In other words, laboratory serves "to bring the 'real world' into an otherwise theoretical education" (Feisel and Rosa, 2005, p. 123).

Build objects. Students can actually build and test their designs. A sense of craftsmanship can be gained. They can learn to use working models to solve engineering problems (Hills, 1984). Models are used in many industrial settings but are often ignored in the education of engineers.

Safety. Safety is a real world issue often ignored in theoretical courses. Safety should always be considered in designing experiments and safety rules should be rigorously enforced in the laboratory.

Discovery. Students can discover results which can improve theory and reinforce their ability to predict the results of using complex devices.

Equipment. Students can work with modern equipment, which adds a concrete aspect to an otherwise abstract education. While working with equipment, students can also learn about the importance of safety.

Motivation. "The theoretical work was difficult—some of it exceedingly so—but the physical *doing* made it seem worthwhile" (Florman, 1987, p. 8).

Teamwork. Many laboratories are team efforts, and students can learn to function as part of a team. This can include an opportunity to be the team leader.

Networking. Students may have to find information from a variety of sources including industrial contacts, professors not connected with the laboratory, technicians, and so forth. This is an appropriate experience before accepting their first industrial position.

Communication. Both written and oral communication skills can be emphasized through preparation, progress, and final reports.

Independent learning. Since all the knowledge needed for laboratory classes will not be at their fingertips, students will have to independently review old material and learn new material. This can help prepare them for the real world where independent learning is important.

We have not tried to be encyclopedic, and there are obviously other purposes for laboratory courses (e.g., Feisel and Rosa, 2005; Heywood, 2005; Sheppard et al., 2009).

9.3.2. Laboratory Structure

The structure of the laboratory should depend upon the major purposes of the course. It can range along a continuum from a totally structured, cookbook-type approach to a partially guided experience to an unstructured class. A cookbook approach can be satisfactory if the purpose is to develop psychomotor skills and the ability to use measuring instruments. These purposes have become less important as easy-to-use digital instruments have replaced analog instruments which often required considerable expertise. However, learning to use instruments or tools is still a legitimate purpose for a laboratory course. A cookbook approach may be used when the purpose is to reinforce theory, but a discovery approach is more effective.

In an unstructured laboratory students are given fairly general instructions or goals. The goal may be to design and build a new logic circuit, to survey a new subdivision, or to scale up a chemical process. The students must decide what needs to be done and how best to do it.

An unstructured laboratory might ask students to explore a phenomenon such as the effect of pH and temperature on a biochemical reaction. No other directions are given. Unstructured laboratories are certainly appropriate for seniors who are mature enough to handle the uncertainty and who need the experience in planning and decision making before graduation.

Lower-division students may be lost in an unstructured laboratory. A partially guided experience is appropriate. A student is given some guidance in setting up the experiment and told what to do first. For later parts of the experiment much of the detail is left to the student. For example, a student can be told to look at the effect of several temperatures in a given range but not be told how many or which temperatures to use. In addition, the student would not be told what to expect although he or she might be told to predict the behavior.

Laboratory experiments appear to be most effective when the solution is not known ahead of time (Heywood, 2005). Measuring an orifice coefficient when fifty other students have already done so is not the stuff of a marker event. As a professor you need to be creative. Assume, for example, that the method of measuring an orifice coefficient is important in a fluids laboratory. The method will be learned much better if the student is given a noncircular hole as the orifice. Where does one look up the orifice coefficient for ellipses, rectangles, parallelepipeds, and triangles? What about five- or six-pointed stars and quarter moons? By varying the dimensions and the shapes, each student group can do a unique experiment, and the groups will not be able to dry-lab the results. In addition, this sort of "research" can eventually result in a technical note. Being the coauthor of a technical note or presentation (even if it is in a student magazine or at a student convention) will make the laboratory a marker event for the students. If time is available, this type of laboratory experiment can be made even more useful by asking students to predict the behavior of their orifice ahead of time.

Laboratory classes can be structured to reinforce lectures not with cookbook exercises but with the scientific learning cycle or with Kolb's cycle (see Section 15.2 or 15.4, respectively). Do the laboratory work before the topic is covered in lecture and have the students explore the phenomenon. Let them discover many of the characteristics of the device. For instance, in the orifice example the students can determine the general form of the equation relating velocity to pressure drop. Then in lecture the theoretical development will be much more believable and would already have been partially verified. The students will be more likely to appreciate the power of theory to include additional terms without needing additional experimentation. The lecture would be the term introduction step in Figure 15-1. For concept application students can use their data to determine the orifice coefficient and solve additional problems.

Process-oriented design laboratories (e.g., chemical, industrial and nuclear engineering) typically ask students to design a large-scale apparatus or process. The purpose of the laboratory is to determine coefficients or efficiencies needed for the design. Students must determine what must be measured and must allocate their time between laboratory experimentation and design calculations. Unfortunately, a substantial minority of students have difficulty determining what key experiments will be useful (Heywood, 2005). Product-oriented design laboratories (e.g., civil, electrical, and mechanical engineering) often have design, build, and test projects. Balmer (1988) believes students should solve real industrial problems and test their solutions in the laboratory. An alternative is to have the students design a product that does not exist and test it in the lab.

9.3.3. Nitty-Gritty Details

A number of decisions must be made in any laboratory course. Should the laboratory be part of a lecture course or should it standalone? If the purpose of the laboratory is to reinforce the theory and allow students to discover results, then a laboratory attached to a theoretical course makes sense. Scheduling is easier, and the connection between experiments and theory will be more obvious. If the purpose is to synthesize several theory courses and have students design or build something, then a stand-alone course with appropriate prerequisites makes sense. In either case, the laboratory workload should be congruent with the credit granted. If students are supposed to be able to finish laboratory experiments and reports in the laboratory, then it needs to be structured so that at least the better groups can do this.

Should students work individually or in teams? Although there are a number of reasons why teamwork is beneficial to students, the decision is often made on the basis of availability of apparatus. Equipment availability often determines team size, but most schools seem to have settled on two students for bench scale equipment, and three or four students per group for larger equipment. If teams are used, how should they be selected? It is better to make a rational choice than just to continue what has been done for many years (see Section 9.2.2).

Require students to plan their experiments in advance. Many laboratory courses require students to pass an oral readiness quiz before they can go into the laboratory. This is a good safety precaution which encourages students to think before experimenting. In a design laboratory with projects lasting four weeks, we found it useful not to allow students to collect any experimental data during the first class. This time was spent in planning.

What types of records should students keep, and how should they report their results? Laboratory notebooks are commonly used in industry to support possible future patent claims. Engineering laboratory is the best place to practice keeping a neat laboratory notebook that follows industrial practice (McCormack et al., 1990). Since communication is often an important goal of the laboratory (and all too often of *only* the laboratory), both oral and written reports are often required. The best feedback for oral reports can be provided by recording student presentations on video and having them watch themselves--even writing a brief "review" of their performance (see Section 8.2.5). For written reports the most improvement in writing will occur if students receive prompt feedback and then rewrite the report for a grade. This obviously requires proper scheduling of the laboratory session and diligence on the part of the instructor.

The quality of the equipment in the laboratory is a never-ending problem, and obsolete equipment and poor maintenance can cause difficulties when programs are accredited. We do not see any substitute for modern instrumentation. Components such as resistors and transistors and major pieces of equipment such as nuclear reactors, distillation columns, or jigs do not have to be new, but the analytical instrumentation does. For example, retire mechanical balances. If the purpose is discovery, much of the equipment can be simple and homemade. If the purpose is to familiarize the student with industrial equipment, use commercial equipment. There is no substitute for a planned and funded maintenance and equipment replacement program. Safety should be a primary concern when equipment is repaired and when new equipment is purchased. Safety needs to be stressed with undergraduates (and with TAs). Stern measures are taken in industry when workers fail to follow safety rules, and stern measures should be taken with students who do not follow safety rules.

Teaching assistants may try to avoid laboratory assignments because they are often more work than grading papers in other courses. The department needs to be sure that the workloads for all TA assignments are appropriate and roughly equal. Laboratory TAs usually have significant contact with the students; thus, they should be able to communicate well. TAs often need to be trained, and a convenient time to do this is the week before classes start.

Laboratory courses need to foster both interdependence and individual responsibility (see Section 7.4.2). Each student's grade should be partly based on team results and partly on the individual effort. Encourage groups to make the laboratory a group effort, not merely a leader with two drudges. Professors and TAs should regularly circulate through the laboratory and observe groups at work. After a few weeks of casual observation, it is usually clear who the malingerers are. Regular observation and perusal of laboratory notebooks also help to discourage dry-labbing, which is producing faked experimental results. Students can also be asked to assign part of the grade to the other students on their team. This procedure can work, but abuses can occur.

9.3.4. Advantages and Disadvantages of Laboratory Courses

Laboratory work can provide a concrete learning experience where principles can be discovered. The chance to design and possibly build equipment can serve as a marker event in the student's undergraduate career, and friendships developed in laboratory teams may last for years. In addition, a student may get to know his or her laboratory instructors better than any other professors, and may rely on them for advice and letters of recommendation.

Of course, everything is usually not ideal, and there can be disadvantages. The laboratory may be an incredible time sink as an overzealous professor tries to have the students learn everything about engineering in one course. The equipment may not work or may be obsolete. Files may be readily available, and dry-labbing of cookbook experiments may be rampant. A student's group may malfunction, leaving him or her with all the work and only one-third of the rewards. The professor may be absent, and the TAs may not speak English. Other than tradition, the reason for a laboratory course may be unclear.

The professor, whose task is to make the reality closer to the ideal, can have significant student contact and a chance to make a real difference in students' careers. Design laboratories often require a synthesis of the material from several courses. This helps the professor stay current in areas other than his or her research specialty. Working with real equipment can also help the professor be a better teacher of theoretical concepts.

Grading can be a chore when a number of long reports are turned in. It helps to have someone trained in technical communication available to grade the communication aspects of the reports and to work with students on their communication skills. This reduces the burden on the engineering professors and provides the students with better instruction. Unfortunately, the workload is often heavier in laboratories than in other courses, and less credit may be given for teaching laboratory courses. In the past this unfair workload was criticized by ASEE (1986).

From the departmental point of view excellent laboratories are a source of pride. If you don't believe this, visit a department with an excellent undergraduate laboratory and note the attitude of the professor who guides you through the laboratory. Excellent laboratories also help produce well-prepared engineering graduates. And excellent laboratories are an advantage at accreditation time. Of course, the department gets what it pays for. Excellent laboratories require money for equipment, maintenance, a technician, and dedicated professors, who will remain dedicated only if suitably rewarded. Departments that neglect the laboratory as a way to save money when the budget is tight will pay the price of less-than-excellent laboratories fairly quickly.

9.3.5 Remote Laboratories

Remote laboratories are a relatively new development (Aktan et al., 1996) that have caught on rather quickly. In a remote laboratory setting students use a computer to control a live experiment that is in a different physical location. Students can use a remotely controlled camera to observe the experiment (Sanchez et al., 2004). Since many industrial facilities such as nuclear power plants, modern chemical plants, and robotic manufacturing are controlled remotely, use of remote laboratories provides students with experiences that can transfer to work settings. Remote laboratories allow institutions to share expensive equipment (Guo et al., 2007; Le Roux et al., 2010), reduce equipment down-time, and allow students to do the lab either synchronously (Feisel and Rosa, 2005) or asynchronously (Jernigan et al., 2009). Synchronous operation coupled with a video of the experiment in operation will feel most real to students; however, time on the apparatus will need to be scheduled in advance if the equipment is heavily used. Remote experiments should be used in conjunction with in-person labs since there are aspects of laboratory learning that are not well covered in remote labs. It is easier to impress the importance of safety and obtain compliance with in-person labs. Of course, remote labs will do a better job than in-person labs teaching students to operate in a remote environment.

Because of safety concerns, remote nuclear reactor experiments are run a bit differently than other remote labs. "It is the responsibility of the guest institution to make sure that experiments performed remotely on the host reactor are sufficient to meet their course objectives. On the other hand, all safety, security, and other regulatory considerations are mainly the responsibility of the host reactor. Therefore, the link between the host reactor and the guest institution should not allow access to any of the host reactor controls" (Malkawi and Al-Araidah, 2013, p. 514). Despite these restrictions a survey of their students after the students had been involved with a remote nuclear reactor experiment showed that the students thought the remote learning experience was comparable to on-campus face-to-face experiments.

One concern about remote labs is isolation of a student doing experiments alone (Feisel and Rosa, 2005). Isolation should be less of a problem than for students taking distance education courses on the computer because the student is tethered to the real world. In addition, it is relatively easy to have student groups do experiments (Hoyer et al., 2004).

Remote labs should not be confused with so-called *virtual labs*, which are a form of simulation (see Section 8.3.1). Virtual labs are particularly useful for asking "what if" questions for dangerous situations, but they are not a substitute for in-person or remote labs. When a simulation is used as a virtual lab these five principles need to be followed (Feisel and Rosa, 2005; Vaidyanath et al., 2007):

1. Include statistical variation of the correct order of magnitude.
2. Faithful to the actual experiment—run the experiment in real time.

3. Use the same pre-laboratory preparation and conference as with a real experiment.
4. User-friendly, well-documented software will allow students to run the virtual experiment asynchronously.
5. For an equivalent learning experience, require the students to calculate any parameter values that they would calculate for a real experiment.

The best of the virtual and real worlds can be obtained by having students run one or two real experiments and do related simulations (Heywood, 2005). A very recent modification of remote labs, augmented reality, combines real content with computer integrated virtual content (Andújar et al., 2011). Koretsky et al. (2011) found that combining simulation with real laboratories increased student learning. “Analyses of metacognitive statements of students show enhanced awareness of experimental design, greater references to critical thinking and higher order cognition in the virtual laboratory and an enhanced awareness of laboratory protocol in the physical laboratories.”

Although remote labs are not yet common in engineering education in most disciplines, they have become common in industrial electronics applications (Tawfik, 2013). Based on their economic advantages, we confidently predict that use of remote labs will increase significantly.

9.4. CHAPTER COMMENTS

Design and laboratory classes are important. They provide an opportunity for teaching professional skills critical for the successful practice of engineering. These include communication skills, management skills, and interpersonal skills. More engineers are removed from positions because of a deficiency in these skills than because of a lack of technical ability. Students learn by doing. However, the doing is more effective for learning if it is initially guided and supervised. Thus, we have included teaching procedures which specifically guide the student and provide feedback.

We enjoy teaching laboratory courses. The extra student contact makes up for the burden of grading laboratory reports. In addition, our school has done an adequate job of financing the laboratory and rewarding the participation of professors. Since we enjoy teaching laboratory classes, most students don’t mind taking them from us.

HOMEWORK

1. Determine what roles design and laboratory classes play in the curriculum at your school. Do they meet the spirit of the ABET requirements? If not, what can be done to improve them? Or, why do you think the ABET requirements are irrelevant?
2. Develop a plan to include design throughout the engineering curriculum at your school.
3. Choose one of the methods of teaching design. Outline how to incorporate this method into one of the design courses at your school. Explain how this method would help students achieve the course objectives.
4. Assume one of the design groups in your class is not functioning well. Develop an intervention strategy to help get this group back to healthy functioning.
5. Select appropriate objectives for a laboratory course at your school. Outline a structure to help students meet these objectives.

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CHAPTER 10

ONE-TO-ONE TEACHING AND ADVISING

In a perfect world professors would have the time to get to know every one of their students as individuals and would be able to tutor them when they had difficulties. Although this is seldom feasible, professors do have significant one-to-one contact with students. One-to-one contact occurs when a student asks a question and the professor makes eye contact while answering the question. It also occurs when a student asks a question after class or in the hall, and when a student comes to the professor's office to ask questions. Although brief, these encounters have a considerable impact on rapport with students; thus one-to-one contact has a major effect on the professor's effectiveness as a teacher. One-on-one contact can also have very significant impact on students. Most of our rewarding student interactions have occurred because of one-to-one interactions. See Wankat and Oreovicz (1999) for real examples, but with the names changed.

Advising and counseling usually involve significant one-to-one contact. Many professors have the most contact with individual students serving as research advisers for graduate students.

The one ability common to all these examples is skill in listening. Actively listening and responding is a necessary skill for excellent one-to-one teaching and advising. Unfortunately, this ability is often neglected. Listening skills will be discussed first, and then particular one-to-one teaching and advising situations will be considered.

10.1. SUMMARY AND OBJECTIVES

After reading this chapter, you should be able to:

- Explain and use methods to improve listening.
- Improve tutoring of students and become more effective in helping them learn.
- Improve both academic and personal advising skills.
- Outline your personal value structure for advising research students, and then develop procedures to improve your advising of these individuals.

10.2. LISTENING SKILLS

"You can hear a lot just by listening."
—*Yogi Berra*

Everyone who writes about listening laments the lack of skill in this important communication area. However, learning to listen can be very difficult for professors since many of us really do like to talk. Listening skills are also critical for effective advising and tutoring. If one of the goals of your department is to improve the communication skills of the engineering graduates, then it may be appropriate to teach students to improve their listening skills. Listening exercises can easily be incorporated into laboratory and design courses.

Listening is a skill that can be learned, but practice is required. Listening skills are discussed in many counseling books (e.g., Edwards, 1979; Egan, 2010; Hackney and Cormier, 2012), in many books on teaching (e.g., Eble, 1988; Lowman, 1995; Svinicki and McKeachie, 2014; Wankat, 2002), and in engineering education articles (e.g., Katz, 1986; Wankat, 1979; 1980). Reading about listening skills can be a first step, but significant improvement requires practice.

10.2.1. Setting the Climate

First create a climate that allows listening to occur. To become known as someone who listens, you must be available, and the easiest time to be available for the largest number of students is before and after class. Students must come to class anyway, so the barrier to talking to the professor is significantly less than in coming to an office. Come to class five or ten minutes early. This gives you a chance to make sure that the room is ready for class, but it also sends a subtle message that you are interested and looking forward to the class. It gives students a chance to talk to you. Early in the semester it is useful to walk around the room with a class list, talking to students and learning their names. Later in the semester students will come up to you to talk.

Students often have questions after a class; by staying a few minutes you can further develop a rapport with them. You may have to avoid scheduling a meeting immediately following the class. If the after-class period is too rushed, you might consider finishing class five minutes early. Since you don't want to delay the start of the next class, it helps to be available for short questions outside the classroom. Office hours are useful for longer discussions and for dealing with private concerns of students (see Section 10.3).

Professors and students are not equal—in knowledge, experience, or power. These inequalities in power and status inhibit some students (nothing inhibits other students!). Facilitate student interaction by making the environment more equal. Reduce barriers: Step from behind the podium and take a few steps toward the students. Wander in the audience to solicit interactions with students. Be relaxed and nonverbally encourage students to talk. Sitting down on the edge of a table or desk indicates that you are relaxed and have time to talk. Rearrange your office so that the desk is not a barrier between you and the students. [If you are new to academe and feel a bit insecure, you might want to have the desk between you and the students. Look into proxemics (Hall, 1966) for more on the role of space in nonverbal communication. Also see Section 10.2.3 below.]

Attitude is important. Generally speaking, people who are classified as feeling types on the Myers-Briggs Type Indicator (see Chapter 13) will have an easier time conveying to the students the impression that they want to listen. Thinking types need to consciously think about the students' feelings. Perceptives tend to enjoy the uncontrolled give-and-take of discussions with students, while judging types need to schedule this time. By knowing yourself, you can adjust to be available and to listen to students. A note of caution: If you don't particularly like students but love the content, don't try to fake being the students' friend. They will see through your facade. Aloof professors who are content experts can be good teachers (see Table 1-5).

To encourage interaction with students, be nonjudgmental: There are no "dumb" questions. There are questions that show a lack of understanding, and there are questions you don't understand. The purpose of listening is to clarify your understanding of the questions so that you can help students understand the material. It is also helpful to avoid being defensive. This can be difficult when students are angry and are attacking a test, and may be attacking you. Although there are no dumb questions, there are hostile ones. Sometimes acknowledging a student's feelings (see Section 10.2.2) will calm her or him so that he or she can listen to facts. Sometimes humor is useful in deflecting the hostility. If no progress is made, offer to talk to the student privately after class. Discipline problems are discussed in detail in Chapter 12.

Being nonjudgmental does not mean "anything goes" or that there are no standards. Instead, it means that actions and behaviors are evaluated, not the inherent worth of the student. There are times "when a student is rationalizing about the difficulties and needs to be told bluntly to make an attitude adjustment and work harder (or more efficiently)" (Herrick and Giordano, 1991). When being blunt with a student, tell the probable consequence of actions or inactions, but without a character analysis.

10.2.2. Focus

Your first focus should be on the student. Make eye contact, move or lean toward him or her, offering nonverbal encouragement. Listen to what the student says completely without trying to formulate your response before he or she is finished. Use your brain's "free time" to ask yourself questions about what the student is trying to say. What is the underlying message that may be hidden in the student's response (Katz, 1986)? A useful technique is to paraphrase the question briefly after the student is finished. This ensures that you have understood it, and in a classroom situation ensures that everyone has heard the question. Repeating the question also gives you a little more time to formulate an answer to the question.

The best atmosphere for a class is one where the professor is there to help the students master the objectives. Unfortunately, in many classes the professor is the enemy. Anything that you can do through one-to-one contact to help students feel that you are there to help them learn helps improve the atmosphere in the classroom. How much of the student's problem should be solved by the professor and how much by the student is a judgment decision discussed in Section 10.3. Another trick for focusing on a speaker's message is to take notes. This may help you listen and pay attention at faculty and committee meetings, seminars, after-dinner speeches, and so forth. It is also appropriate to encourage both undergraduate and graduate students to take notes in meetings with you.

There should also be some focus on emotions. Emotions are always present, and if not dealt with directly may prevent communication and learning. This is particularly appropriate in private, but can also be appropriate in a classroom. In class, it is usually sufficient to acknowledge the emotion and then move to the content of the question. For example, "This appears to be an emotional issue for you. Let's look at it from another angle;" or, "I see that you are upset about the grading of this test. Let me answer the question now and then we can discuss the grading after class." In private, spend more time exploring the student's emotions (see Section 10.4).

Although it is appropriate to focus on the student's emotions, it is usually not appropriate to focus on your emotions as the professor. Try to remain rational and nondefensive. This is particularly true in class where an emotional outburst can do significant damage to your standing and credibility. Unwind later by talking to a friend privately.

10.2.3. Responses

Individuals make nonverbal, minimally verbal, and verbal responses to others. An additional response is silence. All these responses should be congruent. Students receive a confusing mixed message if your words do not agree with the nonverbal signals. This is one reason why most people cannot fake interest or caring for long periods.

Nonverbal messages include facial expressions, eye contact or lack of eye contact, interpersonal distance, hand gestures, and body language (Axtell, 1991; Goleman, 1995; Navarro and Karlins, 2008). In Western cultures direct eye contact with occasional breaking and reforming of the contact is expected. Leaning forward is usually interpreted as a sign of interest, as are nods and encouraging hand gestures. An open stance or sitting position is interpreted as signifying openness, whereas crossing one's arms suggests a closed, defensive position. Clenched fists are often interpreted as anger, as are angry facial expressions. These are powerful signals which most individuals raised in a Western culture transmit and receive unconsciously (Axtell, 1991; Navarro and Karlins, 2008). The signals are often so powerful that words are ignored if they are incongruent with the message.

An individual can change the nonverbal messages he or she is sending. Changing behavior often changes the individual's feelings. If you find that you have your arms tightly crossed and you are resisting listening to a message at a meeting, purposely opening your arms and relaxing will probably result in better listening. Since changing behavior often changes underlying emotions, it is useful to monitor and change the nonverbal clues you are sending to your students (see Section 3.3.9). One problem with nonverbal messages is that they may be misinterpreted. For example, the tightly crossed arms in the previous example may simply mean that the person is cold, while it is interpreted as being closed to an idea. In addition, the nonverbal messages of different societies are different (Axtell, 1991). In India shaking one's head from side to side signifies agreement, not disagreement as it does in Western society. The appropriate degree of eye contact and comfortable interpersonal differences are very different in different societies. If you are listening to one of your students and the nonverbal and verbal messages appear to be incongruent, it may be that you are misinterpreting her or his nonverbal messages. And he or she may be misinterpreting your nonverbal messages.

Minimal verbal messages are sounds like "uh" and "uh-huh" and words like "oh," "yeah," and "OK" that do not convey meaning but encourage the person to keep talking. Minimal verbal messages sent by the listener imply that he or she is paying attention and understands the speaker. These messages are often used in private conversation, although they are also appropriate when a student is talking in class. If speakers often act as if they don't know whether you are listening, you may need to increase your use of minimal verbal messages. However, faking minimal verbal messages when you aren't listening will get you into trouble.

Verbal messages are an important part of the active listening process. Probes are questions or directives which ask the speaker to tell more. Probes can be nonspecific, "Elaborate on that" or "Tell me more;" or quite specific, "What would one observe if the weld was bad?" or "You are confused about the application of Kirchhoff's laws in this situation." Probes are often more effective if they are open-ended questions or directives which cannot be answered with a simple yes or no response. If you ask closed-ended questions and get yes or no responses, then change the questions to make them open-ended.

Paraphrasing what the student has said in your own words is useful for letting him or her know that you understand. It is appropriate to ask if your interpretation is correct. Summarizing long statements in both classroom and private discussions is another useful active listening technique: "What I heard you say is . . . " Again, it is important to check with the speaker that the summary is correct.

Silence is not golden if it does not encourage communication or becomes threatening. Use silence to encourage communication, not to punish students. Professors usually do not pause long enough after asking questions. A period of silence is necessary to allow students time to respond. In class this will be less threatening if you do something useful during the period of silence. For example, ask a question, clean off the board, and then turn back to the students for an answer. Silence, perhaps punctuated with a nonverbal response, is also appropriate when a student is clearly processing information and is not ready for more communication.

Silence is very useful when students are trying to manipulate you. A common ploy is for a student to tell all the reasons why he or she will have trouble handing in an assignment on time or taking a test when it is scheduled, but never make a direct request for postponement. Since no request has been made and no question has been asked, there is no need to respond. Silence is an effective counter ploy since it forces the student to be honest about the request. An alternative response is to use a probe such as "Well, what are you going to do about it?" There is a final use for silence. When a student breaks down and starts crying in your office (yes, this does happen), one appropriate response is to offer a tissue and be silent until he or she has regained control. Always have tissue available in your office.

10.2.4. Comparison between Listening and Nonlistening Behavior

Table 10-1 presents a comparison of listening and non-listening behavior that can serve as a checklist for monitoring your behavior or for helping students improve their listening skills.

10.3. TUTORING AND HELPING STUDENTS

We use an inclusive definition of tutoring to include helping students before and after class, during office hours, in special help sessions, in the halls and on the telephone. We rejected the idea of calling this section "Office Hours" since only a fraction of the students in a class come to see a professor during office hours. A majority of students can receive individual attention and at least minimal amounts of tutoring when the professor broadens availability.

We are interested in improving tutoring because experienced human tutors can increase a student's score by approximately two standard deviations (commonly called sigma in this literature) compared to classroom instruction (Bloom, 1984; Zemke and Elger, 2008). Two sigma means an average student can be in the top 2% of the class. Zemke and Elger (2008) note that two sigma is a generalization and measured improvement ranges from 0.4 to 2.3

Table 10-1. Comparison of Listening and Non-Listening Behaviors (Harrisberger, 1994; Wankat, 1979, 2002)

	Non-listening behavior	Listening behavior
Time limitations	Does not mention time, but is obviously busy and tries to shorten the interview	Honest about time limitations
Climate	Defensive and Judgmental—	Open and Supportive—
	1. Evaluates and judges	1. Non-evaluative and non-judgmental
	2. Tries to control speaker	2. Problem-oriented
	3. Uses strategy	3. Honest and spontaneous
	4. Neutral, avoids feelings, or fakes caring	4. Accepts and shows feelings, caring
	5. Shows superiority: sometimes with arrangement of office.	5. Sets up an equal environment
	6. Certain and dogmatic about conclusions	6. Tentative about conclusions
Focus	1. Internal: self-conscious	1. On speaker
	2. External: on other work	2. On speaker's topic
	3. Visual: does not watch speaker	3. Looks directly at speaker
	4. Interaction: on mechanics of conversation	4. On what is being communicated
	5. Telephone rings: answers	5. Does not answer phone: signals student is more important.
Non-verbal behavior	Non-attending: closed posture, expressionless face, faces away from speaker	Attending: open posture, shows facial expressions, looks at and leans toward speaker
Dialogue	No dialogue: either silent or monopolizes conversation, asks closed-ended questions,	Dialogue: reflects, summarizes speaker, clarifies unclear points, asks open-ended questions
Overall	Appears disinterested and bored	Appears interested

sigma or there may be no improvement in learning. Cohen et al. (1982) found a 0.4 sigma improvement (approximately half a letter grade) from untrained tutors. The large variation indicates that significant improvement is possible.

10.3.1. Tutoring Locations

Right before and right after class are the most efficient times for tutoring because many students ask questions then but are not tempted to visit with the professor. Coming to class early and staying late also shows accessibility and interest in the students. This technique is one of the few methods which are efficient and effective for both students and professors, and we strongly recommend that you try it. Since there are minimal barriers to the students, the hall can also be an effective place for informal student contacts. Professors who are open, friendly, and know the names of their students are often asked questions in the hall. Many of these questions can be answered immediately. For questions requiring more time or the use of a board, you can make an appointment with the student or invite her or him into your office immediately. Taking a student with you into your office is one way to encourage students who otherwise would never come on their own.

Office hours are useful for the “regulars” who will use them. Unfortunately, many students, particularly introverts, who could benefit from help, do not take advantage of a professor’s office hours. Directly inviting students to come see you appears to be the best way to signal to students that you are approachable (Griffin et al., 2014). Encourage the whole class to visit both you and the TA during office hours. (Of course, be sure that both you and the TA keep office hours.) Private notes on returned homework and tests asking students to come in and see you or the TA can also be effective. In lower division courses it may be appropriate to tell struggling students that they must come in. This fits in with our general strategy of being more directive to beginning students. Some professors require all students to stop in early in the semester as a way of getting to know them. This also reduces the barrier to students’ coming to see you.

Telephones, Skype, and text messaging can also be used for long-distance tutoring. For television courses at remote sites, telephone, Skype or text messaging contact with students is indispensable. A specified time may be set aside when the professor will be available for phone calls about the course. Most students never use this service, but the existence of the service is important psychologically. Similarly, set-aside hours with the TA or the professor available to answer phone calls or text messages can be used for on-campus students. This service is particularly valuable for commuters who might find it difficult to come in for scheduled office hours. Text messaging can obviously be used at any time, but during these set aside times responses will be quicker. Walton et al. (2012) suggest using Google Voice (https://www.google.com/voice) for text messaging as it allows the instructor to respond in the same way as responding to e-mail and the instructor does not need to use his/her personal phone number. Of course, e-mail is a useful method for communicating with students (Hannon, 2001), but don’t be surprised if students never check their e-mail.

Should you give your cell or home telephone number to students and encourage them to call you? This is your decision. Some professors do this and some do not. If you do, it is appropriate to set limits on when they can call.

10.3.2. Advantages and Disadvantages of Tutoring

Tutoring and lecturing can fill complementary functions, as shown in Table 10-2, but they also differ in their ability to satisfy some of the basic learning principles listed in Section 1.5. This comparison is shown in Table 10-3. A complete course package of lectures, tutoring, homework, and tests can satisfy all the learning principles; however, try to satisfy as many of these as possible without tutoring since many students will not come in for tutoring.

Table 10-2. Comparison of Lecturing and Tutoring

Item	Lecture	Tutoring
Purpose	Transmit information	Troubleshooting
Where done	Lecture hall	Anywhere
Focus	Entire class	One student or small group
Coverage of material	Broad: Use of material may not be obvious to student	Narrow: immediately useful
Emotions	Not dealt with	Can be dealt with
Personal attention	Very little	Lots
Barriers to student use	Scheduled for early morning	Hesitant to bother professor
		Professor may not be receptive
Path	Linear/sequential	Branched/multiple
Information transfer	Mainly one-way	Interactive
Efficiency: Professor	High	Low
Student	Low to medium	High
Professor needs	Basic knowledge Ability to organize material	Basic knowledge Listening skills Tutoring skills
	Presentation Skills	Troubleshooting skills
Advantages	Good at transmitting information	Individualizes
	Efficient use of faculty time	Can work on problem solving

10.3.3. Goals of Tutoring

The definition of good tutoring depends upon the goals of tutoring. The professor's goals are often to make a student a better, independent problem solver. Other possible goals include getting to know students better, receiving feedback about what they understand and do not understand, having an opportunity to interact more with them, motivating them to learn the material, stretching and challenging them, and minimizing the time spent tutoring.

Students often have a different perspective. Many want an answer to their current difficulty and are not concerned about overall development as a problem solver. However, some students are genuinely concerned about learning the course content and want to become better problem solvers. Some use tutoring as a shortcut to finding information that they could clearly obtain on their own. Overly dependent students often want to check that they are doing everything correctly. They want reassurance. Students with a high need for affiliation may want to get to know the professor and use office hours for this purpose.

The dilemma for you is to satisfy your goals and at the same time satisfy enough of the student's goals. Except for highly dependent students, students whose goals are not satisfied

Table 10-3. Satisfaction of Learning Principles

Learning Principles	Lecture	Tutoring
1. Active learner	Often no	Usually yes
2. Feedback	Usually no	Can include
3. Knows objective	Can transmit in lecture	Could check on: seldom done
4. Motivate learner	Can happen: often doesn't	Reinforce motivation
5. Individualize	Difficult	Yes
6. Important types of learning:		
Concepts	Yes	Can clarify
Apply principles	Sometimes	Yes
Illustrate problem solving	Can do	Can give practice
7. Problem solving requirements:		
Acquisition knowledge	Yes	Can clarify
Correct misconceptions	Rarely	Difficult but possible
Practice	Usually no	Yes
8. Structured hierarchy material	Yes	No
9. Thought-provoking questions	Can do	Can do
10. Professor enthusiastic	Can show	Can show

will not return. This minimizes the time you spend tutoring but does not satisfy any learning objectives. Various methods can be used to improve tutoring.

10.3.4. Methods to Improve Tutoring

Tutoring is an art. A tutor must continually make decisions about what will be most helpful for a student at a particular time. Sometimes only a short answer or a pat on the back is needed. In other cases significantly more time is required.

Tutors can individualize the instruction for a particular student. Since different students want and need different things, vary your approach and responses. Observe and listen closely throughout the semester. When you meet their wants, students will be happy and motivated. Unfortunately, this may not satisfy the students' needs. Someone who has trouble generalizing solution methods wants to see the solution method applied to all possible cases. What he or she needs is to learn to generalize. Good tutoring may consist of showing one additional case to satisfy his or her wants. Then the tutor can show how to generalize from the base case to the new case, and follow this by making the student generalize to another new case.

Students prefer that tutors point out their mistakes and show them the solution path. However, Razzaq and Heffernan (2004) note that for effective tutoring, "tutors should not offer strong hints or apply rules to problems themselves when students make mistakes." Students learn more if they reason out the answer themselves. Good tutors should "let the students do most of the work in overcoming impasses, while at the same time provide as much assistance as necessary." The tutor must strike a balance between letting the students find their own path and preventing them from going on a path that is "unproductive and unlikely to lead to learning." Good tutors make numerous brief comments while students are learning, but it is important that the tutor *fade*, removing some of the support, as the student demonstrates proficiency. Usually, there is a remedial response for every student error, but with more advanced students the tutor might delay feedback to give the student a chance to find and correct the mistake. Excellent tutoring requires judgment. Change the questions and comments if the student repeats an error. Untrained tutors and professors tend to give lengthy explanations or answers, but these do not correlate with deep learning (Zemke and Elger, 2008). Instead, tutors need to be taught "to substitute open-ended content-free prompts for explanations." For example, "What will you do next?" Or "What are you trying to determine?"

In Section 15.2 we will see that people construct their own knowledge structure. One of the modern tenets of helping people learn is to start with the student's preexisting knowledge structure, and if the structure is incorrect to work to correct misconceptions. Unfortunately, untrained tutors "routinely overestimated what the tutees knew correctly and underestimated what the tutees knew incorrectly" (Zemke and Elger, 2008). This statement is also true of many professors. Tutor training needs to emphasize *exploring* what the tutee's pre-existing knowledge is and focusing tutoring actions within the tutee's knowledge frame. The four tutoring actions recommended by Zemke and Elger (2008) are:

1. *Refinement*. Prompt correction or refinement of pre-existing knowledge.
2. *Guided assistance*. Provide brief just-in-time assistance as the tutee solves problems.
3. *Problem structuring*. Work with the tutee to develop a structure for problem solving.
4. *Infusing*. Provide calibrated amounts of new knowledge on a just-in-time basis.

Students also require different emotional responses. One student may respond to a challenge, while another may require initial hand holding and encouragement. Some students respond well to the Socratic approach; others become flustered and frustrated. What works best also varies from day to day. Right after a difficult test is not the time to offer another challenge. By observing and listening to a student, you can get an idea of his or her emotional state. Then respond accordingly.

One important way to improve tutoring is by improving listening skills (Section 10.1). Be nonjudgmental. It doesn't help a student when he or she is yelled at and called stupid. This requires patience. Without jumping to conclusions, try to find what the student's difficulties really are. Ask open-ended questions to help the student find her or his own mistake. Whenever the problem is nontrivial, encourage the student to talk. Some focus on emotions can be helpful. A very short comment such as "I see you're really frustrated" can have a remarkable effect. It frees up the student, helping her or him see you as human and to feel that you understand.

Listening is particularly important when a student has subtle misconceptions. Conceptualize what the student is thinking and compare his or her approach to possible correct approaches. Since words can hide the student's misunderstanding, ask the student to write equations or draw a figure. This can help you see what he or she is talking about.

Interest in helping students is another important ingredient in excellent tutoring. You have to want to help students, although the reason why you want to help is probably not very important. Interest is important because a student can sense it from many verbal and nonverbal clues. Interest is also important as a motivating force for the professor. Tutoring can be hard, frustrating work. Being interested in helping students provides the patience and energy needed to be an effective tutor.

When a student comes in for tutoring, the passive lecture approach has not worked. Make the student do things—explain an approach in detail, write equations on the board, or solve problems on paper. Involve the student in the process instead of giving another mini-lecture. After you explain something, don't accept the polite but often meaningless, "I understand." For example,

Professor:	Do you see it now?
Student:	Yeah, I understand.
Professor:	Good, now finish this problem on the board.
Student:	You mean right now?

This forces the student to become actively involved. It also allows you to observe and correct mistakes as they occur. Give minor help, and allow the student to work the problem through to completion. This can provide confidence that he or she can solve the problems. This procedure works in the student's *zone of proximal development* where, with help, problems can be solved (Section 15.5).

Another way to make the student be active is with probing questions that eventually lead her or him to the desired solution. Unfortunately, in our experience this does not work with all students. When it does work, it is a fine method for making the student reason his or her way through a problem.

Another method is to have the student explain your answer in her or his own words. Sometimes you'll answer one student's question and then have a second student come in and ask the same question. Ask the first student to explain the answer to the second student. This forces the first student to be active, gives you a chance to check on understanding, and fulfills the learning principle of having students teach.

Students often know concepts but are unable to use them to solve problems. Since problem solving is an art, the one-to-one contact of tutoring can help students improve their techniques. Many students have no idea how they or anyone solves problems. When tutoring, use the problem-solving strategy taught in your course. This may involve only one or two steps of the strategy or may involve going step by step through an entire problem.

For example, when a student is having trouble getting started, going over the Define and Explore steps is appropriate (See section 5.4).

Professor:	OK, let's define the problem.
Student:	Well, it's written down here.
Professor:	Go to the board and draw me a figure.
	Good, now label all knowns.
	OK, what are you asked to find?
	Good, that defines the problem. What's the next step?
Student:	It's to explore.
Professor:	What does explore mean?
Student:	Look for different possible approaches.
Professor:	Right. Give me five different ways you might be able to solve this problem.
Student:	Five?

Professor:	Uh-huh. If you only have one, you're not exploring.
Student:	Well, I could . . .
Professor:	Good, now let's go on and work on the most likely approach. Which approach is most likely to work?
Student:	I think that the . . .
Professor:	Fine. Now let's plan how you would do that.

This approach does not produce an experienced problem solver immediately. However, it does guide the student toward improving.

When a student has put in considerable effort but is not converging on the right answer, troubleshooting is called for. Knowledge of typical student mistakes is helpful. Beginning students often have trouble with unit conversions or forget to convert units. A brief study of tests and homework will show you what the typical errors are in your subject.

If the difficulty is not a typical mistake, then more subtle errors must be searched for. This is where expert knowledge of the area becomes important. An expert can evaluate different approaches and find subtle errors. Really excellent tutors must be subject matter experts, but not all subject matter experts are good tutors. How many times have you heard some variant of "He really knows the material, but he can't get it down to our level"? Good tutors need knowledge of the subject, but do not have to be experts. The other ways to improve tutoring appear to be more important than becoming a subject matter expert. This is why students often make good tutors.

Several little tricks can help in tutoring. Professors with a good sense of humor are well liked even if they are hard taskmasters. Humor can defuse anxiety, making learning fun. Groups of students can often be tutored at the same time. Since they often have similar difficulties, students can learn from others' questions. The exception to this is the student who is totally lost and needs individual attention. A final suggestion is to talk to your colleagues or consult with your university's learning center. Find out what works for them with particular students.

10.3.5. Tutoring Problems

Good tutoring with students who are initially lost is a slow process. Thus, finding enough time is the number one problem. How do you find enough time to prepare lectures, tutor, do research, attend committee meetings, and do everything else which needs to be done? Tutoring requires time, and it helps to be efficient with other tasks (see Chapter 2). One method which can help you control your time is to set specific office hours for tutoring. Unfortunately, this solution can generate a new problem. What do you do about students who come in at times other than your office hours? One possibility is to respond, "I'll help you this time, but in the future please come during office hours." Alternatively, if you cannot help right now you can respond, "I'm sorry, I can't meet now. Let's check schedules and find a time to meet." Perhaps the problem is you have picked office hours that are not convenient for students. Ask the students what hours would be most convenient for them.

The overly dependent student is another problem. To become an independent problem solver this student needs to be weaned from the professors. The student is probably getting what he or she wants, but not what he or she needs. One approach is to discuss dependence with the student. This needs to be done in a nonjudgmental fashion. For example, tell the student that employers expect their engineers to be relatively independent, and that you are worried that he or she is not learning this skill. If the dependent behavior persists, you may have to limit the student to a specified number of minutes per week. This ploy is most effective if every professor who has the student agrees to this treatment. Fortunately, this extreme behavior is rare.

The opposite problem is the extremely shy student who may not ask for help even when he or she would benefit from it. Encourage the student. If this student does come in, force yourself to listen even if you are very busy. One interpersonal mistake may drive a shy or sensitive student away. For a shy student to go to a professor's office is an act of courage. By being too busy or locking your door you may destroy this courage.

10.4. ADVISING AND COUNSELING

Probably the most neglected area in engineering education is advising, and certainly this is the area where students show the least satisfaction (Wankat, 1986; Panitz, 1995). Before ABET-2000, inadequate advising was a commonly cited deficiency during ABET accreditation visits. Eble (1988) called advising in college "a mess." Hewitt and Seymour (1992) found that inadequate advising was a frequent complaint of students who left engineering. Schwehn (1993, p. 11) stated "Few believe that academic advising should be rewarded; it seems to almost all faculty an irksome task at best." Twenty years ago these negative comments were all too often valid. Since the first edition was published, we believe that advising has improved significantly at many schools. One way many schools improved advising was to remove most advising from professors, who usually placed advising a distant third behind teaching and research, and placed advising in the hands of people hired to be advisors. At these schools professors and advisors will both be more effective if they work together. At institutions where professors do extensive advising some knowledge of how to improve the process will be helpful. In this section we will first discuss academic advising and then helping students with personal problems. Professional counselors often draw a distinction between advising and counseling, but we will use these two terms interchangeably.

10.4.1. Academic Advising

Advisors need to be trained to do academic advising (Drake et al., 2013; Wankat, 1986, 2002). This is true for professors, peer (student) counselors, administrative assistants, and professional counselors. Training is required for the specific information needed, in listening skills, and in specific counseling skills. Unfortunately, only about a third of US campuses provide faculty advisors training while only a fourth of the campuses require training (Habley, 2000). Model training programs for faculty, peer counselors, and professional counselors will be different because each group has different needs (Farren and Vowell, 2000).

Studies (e.g., Light, 1990) have found that there are significant gender differences in what students want from their academic adviser (Table 10-4). To some extent they may mirror differences in the percentages of men and women who are feeling or thinking types according to the Myers-Briggs Type Indicator (see Chapter 13). The implication for advising is that procedures that work for men may not satisfy women. Tannen (1990) notes that in general men communicate facts and try to maintain independence, whereas women search for rapport and connections. Within this general framework Table 10-4 makes sense.

Table 10-4. What Students Want from Their Academic Advisor (Light 1990)

		Men	Women
1.	Will take the time to know me personally	30	72
2.	Shares my interests so we have something in common	31	58
3.	Knows where to send me to get information	48	51
4.	Knows the facts about courses	64	43
5.	Makes concrete and directive suggestions	66	23

Note: Table shows percentage of respondents saying "very important."

First, an adviser's information must be accurate and up-to-date as to the university's requirements for registration, prerequisites, dropping and adding courses, probation, transferring to a different college within the university, grade appeals, and so forth. The adviser needs to be able to tell a student the consequences of doing or not doing something. If the adviser does not know an answer, he or she needs to know whom to ask to find out. At large universities keeping up to date is a nontrivial task since courses, graduation requirements, and rules are continually changing. Advisers probably need to attend a meeting every semester to refresh their memories and to learn about changes.

A major role of advisors is to provide referrals. Offices that advisors may want to refer students to include:

- Career center
- Cooperative education
- Disability student assistance
- English as a Second Language (ESL)
- Financial Aid
- Immigration
- International students
- A campus organization or club where the student where will feel he or she belongs. Light (2001, p. 98) states this is often "the single biggest contribution an adviser can make."
- Study abroad
- Transfer advising
- Tutoring
- Veteran's affairs
- Writing center

Resources for students with serious problems are listed in Section 10.4.2.

Each school has a slightly different philosophy about advising. We believe that the responsibility for obtaining an education is the student's. The adviser is there to help, provide information, and explore alternatives, but the student retains the ultimate responsibility. Thus, advisers need to help students gradually become more responsible in such things as checking for errors on a schedule, selecting a major, selecting electives, getting to know a few professors well, and eventually deciding upon graduate school or an industrial position.

Since the ultimate responsibility lies with the student, we recommend a relatively nondirective approach until it is clear that a proactive stance is needed. Let the student do most of the talking while you listen, empathize, probe, tell the student the probable consequences of a particular action, and then let the student make the decision. Of course, there are certain actions, such as taking a course without the prerequisites, which may not be allowed, but if the action is allowed, the student should make the final decision. The adviser's expertise is important in explaining the consequences of actions. For example, many students are unaware of the consequences of being dropped from the university. Or, a student may not realize that dropping a particular required course will delay graduation by one year.

Many lower-division students are not ready for the responsibility of conducting their own affairs. A fairly proactive or prescriptive stance is appropriate for lower division students when there are signs of problems, such as excessive absences, D and F grades, probation, failure to register on time, and so forth (Drake et al., 2013). Phone calls, e-mails, letters, and personal visits can help prevent a student from getting into serious trouble. Students often just let things go because they do not understand the probable consequences of their actions. A formal written contract with the student may be appropriate (e.g., to find a tutor). Since the student is irresponsible, the adviser needs to keep notes on what has happened and what agreements have been made.

With freshmen and sophomores it is appropriate to discuss academic skills if students are having problems. Engineering professors often assume that students know how to study and understand the tricks of taking tests. Many students have not learned these skills. Study methods, problem solving, test taking tricks, relaxation methods, and methods for budgeting time can all be useful to such students. These academic survival skills can be covered informally in small groups, and students can be encouraged to form study teams. Many universities have these types of programs available through a counseling office or the psychology department. Learning these methods and skills requires that students construct the knowledge necessary (see Chapter 15), and practice plus feedback are essential.

Upper-division students are likely more mature, and with them a more laissez-faire approach is often appropriate. There are skills which these students probably have not learned that will be useful. In particular, interview techniques and decision making are of considerable interest to seniors. These can be taught in seminars or small groups. Individual attention with a professor who is familiar with a given industry or with several graduate schools can be extremely helpful. Although students want to hear the professor's opinions, it is still important to listen to them and let them make the decision.

At large universities it is surprisingly difficult to be sure that all or even most students understand what they are supposed to do for registration, dropping classes, company interviews, and other official tasks. Try a variety of different modes of communication. Seminars, announcements in class, bulletin board announcements, letters, e-mail, learning management system, catalogs, advertisements in the student newspaper, and individual discussions will each reach a few students that the others won't. The failure of a student to know the rules is not an excuse, but try to reach as many students as possible. Since this problem reoccurs every year, patiently keep trying to communicate.

Advisers often spend a great deal of time on routine matters such as registration. There are ways to make this and other routine matters more efficient. Records should be computerized to remove this burden from the advisers. Registration can be handled efficiently by the combination of a group seminar and/or mass e-mail to provide information and individual sessions with the counselor for final course selection. Individual sessions are important to avoid losing students and to give the adviser an opportunity to question the student's course selections. Some students sign up for inappropriate courses for a variety of reasons. The adviser can catch this by asking questions.

Hiring a professional counselor, empathetic administrative assistant, or peer adviser (an upper-division student) can be a cost-effective way of reducing the burden on engineering professors while simultaneously increasing the effectiveness of advising (Panitz, 1995). The routine bookkeeping, processing of forms, and enforcing of discipline do not have to be done by professors. They can better spend their time advising students on professional decisions involving the choice of electives, graduate school, or industrial jobs. Students generally rate professional advisors highly on information about curriculum and which courses to take (Sutton and Sankar, 2011). They are less satisfied with information about which professors would be better teachers, who to choose as a mentor, and what alternate majors should they consider. Professional advisers and professors need to work together to maximize the positive effects of good advising such as better retention and more satisfied students.

Students are also likely to ask their advisor or any professor they get to know about career opportunities. The first place we send students is to our university's career center. For additional information the internet is a good place to start. An excellent source for resume preparation is the Purdue Online Writing Laboratory (OWL), https://owl.english.purdue.edu/owl/. For written material about job searches, interviewing, negotiating, networking, and so forth check out the Purdue Center for Career Opportunities online guide, http://crmpubs.com/CGsFinal/Purdue_CPG13-14_Online/Purdue_CPG13-14_Online.html. For a source with a number of good quality videos on various aspects of job hunting have your students check out the York University Career Centre, http://www.yorku.ca/careers/cyberguide/introduction.html.

At large universities many students seldom have the opportunity to speak individually and confidentially with any university employee—with the lone exception of advisers. It is important for advisers to be open and take advantage of this opportunity. Use of listening skills and empathy may lead the conversation from a rather mundane presenting problem to more serious concerns. The term "presenting problem" refers to a problem that is raised by the student but which may conceal another problem—the one needing to be addressed. Oftentimes an adviser is the only official at the university who has taken time to listen. This caring can make a major difference in the student's career, and many times is what keeps a student in school. Doing this requires interest, time, and counseling skills, which are the subject of the next section. Bullard (2008) discusses the human side of advising in detail. She recommends that advisors:

- Learn and use all of your advisees' names.
- Take time to chat about the student's summer plans, family, hobbies, etc.
- Put a clock in a place where you can easily see it while chatting with students.
- Let the students see that you are a real person with a life outside of work.
- Show the students that you *care*.
- Organize your job and train assistants so that you have time for students.

10.4.2. Counseling Skills for Personal Problems

Advising students on personal problems is not, and in our opinion should not be, a major role of engineering professors, but it is sometimes required. The procedures used for dealing with personal problems are often useful for academic and career counseling. A simple crisis intervention model useful for short-term interventions will be presented (Edwards, 1979; Wankat, 2002). Professors should always aim for short-term intervention with students with one or at most two sessions. If the professor has a student in class, then great care should be taken in counseling him or her on personal problems. The roles of teacher and personal counselor are in many ways incompatible (Lowman, 1995). Professors should be aware of the resources on campus so that they can refer students to additional help. Useful offices to look up on your campus are those that deal with the following issues:

- Academic regulations and policies
- Community crisis center
- Counseling center
- Dean of Students
- Emergency response team
- Health center or hospital
- Financial aid
- Psychiatric services
- Sexual harassment/assault support services
- Student conduct office or Dean of Students office
- Student legal services

An ABCF model can be used to help students deal with a crisis (Edwards, 1979; Wankat, 2002). The four steps in this crisis intervention model are:

A. Acquire information and rapport. Students who come in to talk to an adviser very often have a presenting problem which is the first thing they talk about. The presenting problem is real and often is the only problem. However, there may be other problems hiding behind it, which the student would like to talk about if given the opportunity. Advisers who are open and use listening skills give students the opportunity to discuss these deeper problems. In addition, there are often other signs of serious problems that can sometimes be noticed by casual observation: excessive absences, sudden plummeting of the quality and quantity of work, the smell of alcohol on the person, slurred speech, and so forth (Civiello, 1989).

Once it is clear that there likely is a problem, the adviser uses active listening skills to acquire information and establish rapport with the student. Empathy, which may be crucial for gaining rapport, involves knowing what it is like to walk in that person's shoes. It can be obtained by focusing on feelings since the feelings of sadness, anger, fear, happiness, and so forth are universal. The adviser may not have been in a situation similar to the student's, but he or she will have felt similar feelings. With this focus on feelings some students may become quite emotional and start crying. Signify that this is OK, give the student a tissue, and let him or her cry. The short book by Mayeroff (1971) is useful for insights into empathy and caring.

Individuals often skirt taboo subjects, but they probably want to talk about these issues. It is permissible to bring up issues such as death, AIDS, suicide, poverty, and broken relationships. (This can be difficult for the teacher who has to evaluate performance in class.) If you bring up a topic that is not the problem, the student will correct you. Probe, but encourage the student to do 90% of the talking.

The classic error of people learning to use this model is to go too fast in the acquiring step. Often counseling should stop at the acquiring step. People, particularly women, may want a confirmation of feelings, not problem solving (Tannen, 1990). This behavior is more likely to occur with peers who are of equal status than with students.

B. Boil the problem down. Sometimes the student knows what the problem is and sometimes he or she has not accepted what the problem is. If it seems clear to you that the student knows what the problem is, it is OK to ask, “What’s going on here?” Follow this with silence to give the student time to collect her or his thoughts. When the problem is unclear, an important function of a counselor is to help the student clearly state the problem. While in the acquiring stage you can hypothesize about the problem. Then explore if this is a possible problem by probing with open-ended questions. When there is sufficient evidence, formulate a problem statement and check it with the student. Do this in a tentative fashion. “It seems that the underlying problem is . . . ” If the student agrees or modifies the statement slightly, then you are ready to move on to step C. If not, return to step A.

C. Coping: help the student cope. If we think of working with students on personal problems as problem solving, then steps A and B are the define stage. Step C consists of explore and plan stages. The adviser helps the student devise a plan to cope with the problem. Since it is the student’s problem, it is not helpful to give advice. Explore alternatives and try to get the student to set up an action plan. This may be difficult.

There are problems in which the situation cannot be changed but must be accepted. For example, a death in the family or a parent who is dying of cancer do not have solutions. However, there are actions that may help the student, such as joining a support group, seeing a professional counselor, obtaining extensions on assignments and exams, or taking incompletes in classes. Explore these possible actions.

As a counselor you can serve as a resource person during the coping step. Students often do not know what resources are available on campus or in the community. They can be referred to the university counseling center, the office of the dean of students, the student hospital, the financial aid office, the local crisis center, or whatever else is appropriate. It may be helpful to call the referral office and make an appointment for the student with her or his permission.

F. Follow-up. The student needs to go out and actually carry out the action plan. It is sometimes appropriate to schedule one follow-up session to check on his or her progress and offer encouragement. This follow-up can be suggested informally (“Stop in and see me when you’ve gotten this resolved”) or formally (“Can you come in and see me at this time in two weeks?”) Whether or not a follow-up is appropriate depends on your judgment.

One paradox of helping is that the more severe the crisis, the less training the adviser needs. Natural caring and empathy are often sufficient for acute problems. Students with long-term chronic problems and dysfunctional students require trained professional counselors, social workers, or psychologists. Refer these students to the appropriate professionals.

10.4.3. FERPA (Family Educational Rights and Privacy Act)

Who can you tell about a student’s difficulties? The answer is heavily influenced by the Family Educational Rights and Privacy Act (FERPA, 2014). This law gives parents the right to inspect their children’s educational record, but at the age of 18 or when the student enters college this right transfers to the student. The law also restricts who the college can share the records with unless the college has permission from the student. FERPA means that professors can only discuss a student's grades with the student's parents with the student's consent. This can lead to some rather interesting discussions with irate parents.

FERPA does allow sharing records without consent to other school officials who have a legitimate educational interest, schools the student is transferring to, the financial aid office, accrediting agencies, law enforcement agencies when there is a judicial order of subpoena, and appropriate officials in health and safety emergencies. Certain "directory" information such as name, address, telephone number, dates of attendance, honors and awards, and date and place of birth can be shared without permission.

Since the interpretation of FERPA requirements varies from school to school, discuss the requirements with the Dean of Students Office if there are questions.

In cases where you are concerned that the student may hurt him/herself or someone else, contact the appropriate office (emergency response team or police department) first and worry about FERPA later.

10.4.4. Learning Communities

Any process that fosters student engagement will increase the retention of first year students. One approach is to build a learning community in which students live, take classes, and study together (Smith et al., 2004). Although generally helpful for most students, learning communities are particularly useful for students such as underrepresented minority or women engineering students who might otherwise be isolated. Since they take the same courses and are often in the same sections, students in a learning community generally find it easy to develop study groups of students in the same residence hall. Students in a learning community also find it easier to become socially adjusted to college (King, 2000; Smith et al., 2004), which will help increase retention (Tinto, 1994). The *How People Learn* model (Section 15.5) shows that most people learn better if they are part of a community of learners.

In many ways learning communities recreate the ambience of a small residential college where everyone lives on campus, eats at a common dining room, and feels comfortable with the college. Learning communities are needed because most students no longer attend residential colleges with a few hundred students per entering class. New students can easily become isolated at large state universities with 20,000 or more students. Students in a learning community are significantly less likely to become isolated.

There are potential unintended consequences of first year learning communities (Jaffee, 2007). The homogeneity that the learning community provides can re-create a high school environment that is not scholarly and inhibits serious study. Although resident advisors are available, the typical lack of older, more experienced students in the learning community also removes normal, informal peer mentoring. Because of the cohesion of the learning community students, they normally adapt well to active learning approaches, but they may resist more authoritarian lecture approaches.

Many engineering programs started learning communities with NSF funds in the 1990s. The programs are successful at increasing retention and graduation rates (Smith et al., 2004; Taylor et al., 2003). This success at increasing retention led a large number of institutions to keep or start learning communities for engineering students, even though these communities are no longer supported by the federal government.

You can help by first supporting the efforts to develop and continue learning communities. Learning communities are often run by the Office of Student Affairs or the Office of the Dean of Students, offices often ignored by faculty. A little support does not take much effort and will probably be very helpful to the success of the learning community. Second, encourage potential and new students to join a learning community. If you want to become more involved a third approach is to volunteer to serve as a faculty advisor or faculty fellow.

10.5. RESEARCH ADVISERS

An extremely important type of one-to-one teaching involves being a research adviser. This role is closer to the tutoring role than that of an academic adviser or personal counselor, although it has elements of all these roles. Engineering research advisers have two major objectives: to help students develop and become competent researchers, and to do research and publish the results. Although usually complementary, there can be conflicts between these two objectives.

Professors are always seen as role models—either good or bad models. This is particularly true for research advisers who need to behave ethically at all times. Unfortunately, ethical problems between research advisers and students are all too common although engineers are not the worst offenders (Swazey et al., 1993). Advisers who adopt and follow the guiding principle "to do what is best for the student at all times" (Wankat, 2002, p. 206) will not have ethical problems.

All students doing engineering and scientific research need to be socialized into the values of scientific research. Although modeling ethical behavior is important, it is not sufficient. There needs to be a continuing discussion in group or private meetings of the high research standards of the group. Examples of group research values include the need to prove that data is reproducible, reporting and discussing all data within the group, and the need to understand data before publishing it. In addition, any research group larger than one person needs to have policies for allocating authorship, citing papers, and acknowledging other assistance. The COSEPUP (2009) brochure and Steneck (2007) are excellent resources for guidance on responsible conduct of research.

10.5.1. Undergraduate Research

A research experience can be extremely valuable for undergraduates, and strong arguments can be made that a senior thesis should be required (Prud'homme, 1981); or if classes are large and resources limited, undergraduate research should be an encouraged option (Fricke, 1981). Research can give students the opportunity to explore a particular topic in greater depth than would be possible in class. The student can receive individual attention from one professor and get to know this person well, which is very useful when the student needs reference letters. Undergraduate research allows the student to "try out" research to see if graduate school should be considered, and it helps the student improve her efficiency, time management skills, and ability to schedule complex projects. Individual meetings with the advisor provide practice in informal technical communication—an important skill in industry. If teams are used, the student will learn how to function in a team.

Most undergraduate engineering students in the United States have little experience in working independently on a large project. Thus, initial supervision needs to be much more structured than for an advanced PhD student (COSEPUP, 1997). An undergraduate may need to be taught laboratory skills which professors normally assume graduate students know. Making a graduate student/post-doc the supervisor of an undergraduate provides for much of the day-by-day assistance the undergraduate needs. In addition, the experience at supervision is useful for the graduate student/post-doc. With this arrangement professors can meet with the team once a week, review progress, and provide ideas.

The selection of projects for undergraduate research is critical. Real problems which push the knowledge level of the student are appropriate. However, the project must be doable in a finite amount of time. Exploratory projects are inappropriate for undergraduates (COSEPUP, 1997). To progress in one semester, the student must have taken the appropriate prerequisite courses. Team projects can be significantly more complex than individual projects. Reporting of results in both written and oral form should be part of the project requirements. If possible, it is very motivating to list the undergraduate as a coauthor of a paper.

Professors need to be aware of the differences between undergraduate and graduate researchers so that they do not expect too much from the undergraduates. Compared to graduate students, undergraduate students usually have limited time, less background in the subject, lack self-confidence in doing research, and are uncertain of their interests (Luck, 1998). However, undergraduates can bring fresh energy and fresh, naïve questions to the project.

10.4.2. Graduate Student Research

In most schools the major goal of research programs, particularly the PhD program, is a research project and the thesis which results. Then the role of the research adviser becomes critical. This role really has no equivalent in undergraduate education, and in many ways it is essentially unchanged from that of medieval tutors. At some schools the research adviser essentially controls when the graduate student graduates, how long the graduate student is funded, what the project is, whether or not the student goes to conferences and so forth. Once the student signs on with a given advisor, he or she may lose many rights. Obviously, the advisor has significantly more power than the graduate student in the relationship.

Unfortunately, engineering advisors, particularly untenured faculty, face a built-in conflict of interest with their graduate students. Professors want to obtain research results and publish papers quickly. Much of the time this goal is aligned with the students' best interests. However, there are times when the best interests of students and the professor's desire to publish quickly are not aligned. For example, internships while a graduate student are extremely helpful for international students who want to obtain a job in the US after graduation. However, internships take time and students' progress on their thesis research normally stops. A second example is senior graduate students who have learned to be independent researchers and are now rapidly obtaining results and writing papers. These students are probably ready to graduate, but then the professor will lose a very productive team member. The professor who always does what is in the best interests of the students will avoid conflicts of interest and be on the right track.

There will always be a few professors who will abuse their power in their relationships with graduate students, and disgruntled students always know how other students are being treated. Thus, departments need to have formal institutional policies that are enforced. Departments that have a tradition of strong graduate committees have a built-in method to control abuse. Graduate students should look for committee members that will provide skills that complement their adviser. Since they will need to obtain recommendation letters from at least three faculty members (see Appendix A), graduate students need to start networking with these or other faculty. New professors need mentoring in becoming research advisers since they have probably had only their own adviser as a role model.

In engineering most graduate students doing research receive support. Policies on how long the student will be supported to the MS and to the PhD are useful to ensure uniformity. Such policies also help prevent advisers from keeping students too long and prevent students from abusing the system because they enjoy graduate school. Some leniency in the cutoff date is useful for exceptional cases, but the extra period of support should be limited.

The selection of a research adviser is probably the most important decision an individual makes as a graduate student. Unfortunately, the process is often random and students do not ask the right questions (Amundson, 1987). A better approach would be to train students in selection processes before they listen to faculty presentations and interview faculty members. Such training could include a discussion of differences in personality type (see the description of the Myers-Briggs Type Indicator in Chapter 13). Students could also be shown various decision methods such as the K-T decision matrix (Table 4-2). To help students develop their decision matrices, consider giving them a list of generic qualities that may be important in an advisor.

It would be helpful for students to also have some understanding of the different roles that research advisers can assume. Crede and Borrego (2012) found that engineering advisors with large research groups (more than 20 students) tended to act as managers of a business. The professor usually did not understand each individual student's project in detail, but understood the big picture of what the group was trying to accomplish. Group funding was high and a large amount of equipment was available. New students were essentially mentored by senior graduate students or post-docs. At the other size extreme, advisors of small research groups (less than 5 students) tended to spend a lot of time mentoring their students, coaching them on research, and socializing them into research. Small groups usually had less access to equipment and fewer peers to turn to for support. Intermediate size groups tended to lie between the two extremes, except that students in groups of 5 to 10 students were more likely to agree that they knew what the professor wanted.

Since mistakes are made in the selection of a research adviser, a uniform policy on allowing students to switch advisors should be followed. Some schools require all students to interview other potential advisers at some specified point such as on completion of the MS. Students who are satisfied with their current advisers attend these interviews in a cursory fashion. This policy protects the students and removes any stigma from switching advisers.

New graduate students probably are not very efficient and do not know how to do a scientific literature survey or how to schedule a long project. All these things need to be taught. Thus, there is a strong tutoring aspect to starting new graduate students and advising needs to be rather structured (COSEPUP, 1997). At the beginning of the graduate student's tenure as a student, it is useful to have regularly scheduled meetings. Even though there may be no research as yet, there are many other things to talk about. Shortly after being assigned an adviser, ask the student to develop a project plan for when he or she wants to graduate. This makes the student think about what must be done to graduate. The plan can be revised on a regular basis as the student learns more about the time demands of the project. The student also needs to learn to balance the immediate demands of course work and research where there may be no immediate demands. Research requires accepting delayed gratification.

Some discussion with the student about background and goals is appropriate. This will help develop rapport. It is also useful to know where the student has come from (figuratively speaking) and where he or she is going in order to help design methods to motivate the student. Use active listening skills to get the student to talk about her or himself.

The classical graduate student discipline problem involves the graduate student who does not appear to be working or performing any research. Help the student set realistic goals. Sometimes graduate students stop working because they do not have a job lined up after graduation. If this is the case, you may be able to help with a postdoctoral position. If the student is supported by research funds, no work—no pay is a realistic policy. It may be possible to support the student if he or she continues working on research while searching for a job, by delaying turning in the thesis. In extreme cases stopping payment is appropriate.

Palmer (1983) lists the philosophical needs of students as *openness, boundaries*, and an *air of hospitality*. Openness is a sense that there are few barriers to learning. Admit students to the community of scholars and expect them to learn. Firm boundaries help create an open space where students can choose interesting, meaningful research, but not so open that they run wild. Research and learning can be very painful processes since they are not linear paths. Therefore, the learning space must be hospitable. Both new ideas and failures must be treated gently so that the student has permission to keep trying.

10.5.3. Masters' Research

Thesis option masters' research projects in some ways are longer versions of undergraduate research. Since the project must be doable in a finite amount of time, the professor probably needs to define most of the problem. Most masters' students have just made the transition from being undergraduates. Graduation does not suddenly make them mature, self-starting individuals, and many need the same initial structure as undergraduates; however, graduate students should be made more independent fairly quickly. It is appropriate to define the problem but require the student to control the execution of the project. Ask a senior graduate student to train new graduate students in laboratory skills and safety practices. But it is probably not a good idea to use an advanced graduate student as a research supervisor. New graduate students deserve the attention of the professor.

Regular meetings of the graduate and undergraduate students in a research group can help foster a sense of belonging. A senior graduate student can be assigned to organize the meetings. The presentation of research results to the group is a useful practice on a regular basis and makes students more polished when they make formal presentations. New students can be asked to make presentations on papers from the literature. Discussion of the presentations should be critical yet friendly. The professor can ensure that this happens. New ideas should be greeted with the PMI or another positive approach (see Section 5.7.3).

10.5.4. PhD Research

When they graduate, engineering PhDs are expected to be independent researchers: able to analyze a situation, define the problem, outline a plan of attack, and conduct the research. Many companies assume that a new PhD can supervise the work of technicians. In academia the new

PhD will be expected to generate new research ideas, supervise the research of graduate students, write proposals, review papers, teach, serve on committees, and publish. If the PhD is to be able to do all these at graduation, then he or she needs guided practice in doing these activities while a graduate student. This need for practice guides our advising of PhD students.

Since the professor usually has research money for a specific area, the general area for the PhD student's research is usually set. However, within this broad area the student needs to define the problem he or she will work on. This is a nontrivial task. The easy part involves doing a literature search to see what others have done. The professor can help the student by steering her or him to the appropriate tools in the library including computer searches. During this period, attendance at a professional meeting can help the student see what the current hot areas are.

The hard part for most students is the intellectual development often required to be in charge of the research. Determining what is important and what research should be done requires that he or she be relatively mature (see Chapter 14). Most students have always been told what to do, and they initially find the freedom of PhD research frustrating. The period of frustration can easily last a year while they work to determine "what they want." Duda (1984) notes that many students have misconceptions about graduate research, not realizing that research is a problem-solving method and that a straight, linear path seldom works. The backtracking, dead ends, and lack of obvious progress can be frustrating.

Amundson (1987) suggests meeting with students on a regular basis until it becomes necessary to turn them loose. Then they need to be told to work on their own until they come up with something that is new and/or surprising. Most students respond amazingly well to this charge and develop independent ideas. A few start their graduate programs already independent and use the freedom to develop research on their own. A few are unable to cope and probably should be encouraged to look elsewhere for career opportunities.

When a student does present a new idea, it needs to be accepted but with the challenge that it be further developed. Ask the student to develop the idea and then prove it theoretically or experimentally. Suggest that he or she develop ten or twenty alternatives to the idea. Refuse to judge the idea since the student needs to learn how to do this.

While conducting research, a student needs to learn to do a host of other tasks. Foremost is learning to communicate. Encourage the student to review the literature and then write a review article with you. This is efficient since it accomplishes the necessary review process, helps the student learn how to write, and earns the student a publication early in her or his graduate student career. The review article can be completed before the student is challenged to become independent. Communication includes oral presentations. Students can be required to make oral presentations in group meetings and later at professional society meetings. These presentations need to be evaluated to help the student improve. Video recording some of the group presentations is a good way to encourage growth. Students should be given the opportunity to review papers and proposals, first as a supervised activity where the professor also reviews the paper or proposal and the reviews are compared and contrasted. Then, the student can review papers and proposals independently. Pace these tasks over a long period so that the student is not overwhelmed at any one time. And there needs to be plenty of freedom to learn to think; otherwise, students may escape from thinking into mindless work on other tasks.

After a student has learned to conduct research independently, he or she can help to supervise undergraduates. This supervision itself should initially be supervised. Have meetings with the PhD student, both individually and with the undergraduate student, to discuss the progress of the undergraduate student's research. Your supervision can then be slowly reduced.

After a graduate student has completed some research, he or she will want to write a research paper. Ideally, the first paper should be written at the time the student would write an MS thesis if the student were not going straight to a PhD Take an active role in outlining this paper and in the necessary revisions to the paper. When the reviews arrive, give them to the student. The reviews often provide for reality testing. The student should help with revisions of the paper on the basis of the reviewer's comments. Students should be asked to proofread galley proofs for articles—in our experience students are often more careful proofreaders than professors. Once the student has started doing independent research, he or she needs to become independent in writing papers. After experiencing the first flush of success in publishing a paper, the student may suddenly write several papers. If these are not well done, return them with a note indicating that they are not up to professional standards, but do not provide detailed comments. Rewriting is a necessary part of writing, and the student needs to master this art.

Although it may not be appropriate to place a student completely in charge of writing proposals, he or she can certainly help prepare them. Let the student share the joys or frustrations of submitting research proposals. Discuss with her or him the strategy you use for obtaining research support.

Students who intend to follow an academic career need additional teaching experience beyond being a TA. A course or self-study on teaching methods is useful. The chance to do supervised teaching of a class or seminar is also an excellent experience which far too few students receive (see Chapter 1).

Not all graduate students are happy with their advisors and not all graduate. Graduate students in their first year want to develop a personal relationship with their advisor. In the second and third years they want the advisor to provide expertise, timely feedback, and be available. As they become expert in their research they want their advisor to adjust (Brown and Atkins, 1988). A common error of research advisers is to continue to be directive, to treat the student like an intelligent technician instead of as a professional, and to not provide opportunities for the student to define problems (COSEPUP, 1997). Since choosing a research adviser is probably the most important decision graduate students make in graduate school, a senior professor in the department should discuss with the cadre of new graduate students what sort of things to consider when making the decision. Spending ten minutes on formal decision methods such as the K-T decision matrix (Table 4-2) will be time well spent.

10.6. CHAPTER COMMENTS

The ways that a professor interacts with students in one-to-one situations obviously depend heavily on the professor's personality. Some suggestions have been provided which have been found to be useful.

Section 10.4.3 on learning communities does not fit perfectly in this chapter, but it fits better here than in any other chapter. We placed it in this chapter because faculty should be aware how useful learning communities are and because these programs are often run by advising offices.

The section on being a research adviser is likely to be controversial. Many professors use very different procedures as research advisers. Obviously, there is no one best way to advise research students. We have clearly stated our value judgments and then suggested an advising procedure which follows these value judgments. If readers do the same, then Section 10.5. will have achieved its purpose.

HOMEWORK

1. Set up a role play to practice listening skills. This requires that you have a partner to take the role of a student, and a facilitator to observe the interactions and record both their positive and negative aspects. The observer needs to watch the climate, the focus, and the responses (nonverbal, minimal verbal, and verbal). Several role plays should be done including the following situations:
   a. A student who did poorly on the exam and has been asked to stop by the professor's office.
   b. A student who is trying to obtain extra points on the exam.
   c. A student needing academic advising.
   d. A student with a personal problem which is causing academic difficulty.
   e. A third year PhD student who is not making adequate progress on research.
2. List the rules and regulations for undergraduate students at your university as far as registration for classes is concerned.
3. What is the purpose of PhD education in your engineering field? Based on this purpose discuss what the ideal thesis adviser would do. Then develop a program to make your own advising more closely approach the techniques of your ideal adviser.

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CHAPTER 11

TESTING, HOMEWORK, AND GRADING

For many students, grades constitute the number-one academic priority. Tests, or any other means for determining grades, are the number-two priority. Because of this concern about grades, tests and scoring of tests generate a great deal of anxiety, which can translate into anxiety for the professor. It is easy to deplore students' excessive focus on grades, but this excessive focus is at least in part the fault of the faculty. In addition, a student's focus on grades and tests can be used to help the student learn the material.

Testing and homework can help the professor design a course that satisfies the learning principles discussed in Section 1.5. Students study and solve problems when faculty demand it (Kuh, 2003). Homework and exams force students to practice the material actively and provide an opportunity for the professor to give feedback. With graduated difficulty of problems, the professor can arrange the tests so that everyone has a good chance to be successful, at least initially. This helps the professor approach the course with a positive attitude toward all the students, which in turn helps them succeed. The desire to achieve good grades can help motivate students to learn the material, particularly if it is clear that the tests follow the course objectives. Anxiety and excessive competition can be reduced by using cooperative study groups and straight scale grading. Thought-provoking questions can be used both in homework and in exams to use the students' natural curiosity as a motivator. Students can be given some choice in what they do in course projects.

Although testing and homework can help the professor satisfy many learning principles, they also can serve as a barrier between students and professors, which inhibits learning. It is difficult for students to truly use the professor as an ally to learn if they know he or she is evaluating and grading them (Elbow, 1986). Perhaps the ideal situation would be to completely separate the teaching and evaluation functions. One professor teaches, coaches, and tutors students so that they learn as much as possible. Then a second professor tests and grades them anonymously. An alternate method to approach this ideal can be obtained with mastery tests and contract grading (see Section 7.5). If these alternatives are not possible, there will always be tension between learning on the one hand and testing and grading on the other. In the remainder of this chapter we will assume that you have resolved to live with this tension.

Why does one test and how often does one test? What material should be included on the test? What types of tests can be used? How does one administer a test, particularly in large classes? These are the questions we'll consider in this chapter. Then our focus will shift to scoring tests and statistical manipulation of test scores. Homework and projects will be explored. How much weight should be placed on homework? How does the professor limit procrastination on projects? The professor's least favorite activity, grading, will be considered from several angles. Then, we will explore university grade scales and their effects on students and faculty. Finally, after you think you have finished the chapter, the appendix shows how the same set of raw grades can result in very different final grades.

11.1. SUMMARY AND OBJECTIVES

After reading this chapter, you should be able to:

- Discuss the advantages and disadvantages of different types of test questions. Write test questions using each of the major test question styles.
- Develop a grid to determine the course material to be covered on a test.
- Develop a scoring scheme for each problem and explain to a TA how to score a test fairly. Score a test fairly.
- Determine the discrimination of test questions and calculate z and T scores for students.
- Develop a scheme for using homework and projects as part of a course that satisfies learning principles.
- Develop a personal value system for giving course grades.

11.2. TESTING

Fair tests that cover the material can increase student motivation and satisfaction with a course. As long as a test is fair and is perceived as being fairly graded, rapport with students will not be damaged even if the test is difficult. Unfair and poorly graded exams cause student resentment, increase the likelihood of cheating, decrease student motivation, and encourage aggressive student behavior.

11.2.1. Reasons for and Frequency of Testing

There are many educational reasons for having students take tests. Tests motivate many students to study harder. They also aid learning since they require students to be active, provide practice in solving problems, and offer feedback. Tests also provide feedback for the professor on how well students are learning various parts of the course.

Tests are stressful since they are so closely associated with grades. Stress and pressure are part of college and part of engineering. Mild stress ("eustress" versus "distress") can actually increase student learning and performance on tests, but excessive stress is detrimental to both learning and performance for everyone. Exams can be stressful for the professor because they are so tightly coupled with grades. What can be done to harvest the benefits of tests while simultaneously reducing the stress they induce?

Give more tests!

Giving more tests reduces the stress of each one since each exam is less important in deciding the student's final grade. Courses with only a final or a comprehensive exam make the test enormously important and thus very stressful. If there are four tests during the semester, each one is significantly less important. If there are fifteen quizzes throughout the semester, then each quiz has a modest amount of stress associated with it. Having frequent tests or quizzes also allows professors to ignore an absence or discard the lowest quiz grade.

Frequent testing spreads student work throughout the semester, which increases the total amount of student effort and improves the retention of material. The more-frequent feedback to the students and to the professor is beneficial. Both the students and the professor know much earlier if the material is not being understood. The increased forced practice, repetition, and reinforcement of material aids student learning. A logical response for students who are doing poorly on quizzes is to study more. Because stress is reduced, frequent testing serves as a better motivator for students. The net result is improved student performance (Johnson, 1988). One of the advantages of PSI and mastery courses is that they require frequent testing (see Chapter 7). Frequent exams also provide a more valid basis for a grade since one bad day has much less of an effect.

There is an additional, surprising reason students learn more when there are more tests. This is a phenomenon known as the "testing effect" (Miller, 2011; Lang, 2013). Long term memory, which is a good assessment of what is truly learned, is increased if students are quizzed immediately after learning the material. Multiple choice quizzes were effective, but quizzes involving writing short answers were even more effective. These results were first obtained in psychology lab experiments and then were replicated in a college class.

Frequent tests do have negatives. The considerable amount of class time required may reduce the amount of content that can be covered; however, the content that is covered will be learned better. A considerable amount of time may also be required to prepare and grade the frequent examinations. At least some of this time is available since less homework needs to be assigned when there are frequent exams. Perhaps the most important drawback of frequent tests in upper-division courses is that, although students learn more, they do not encourage students to become independent, internally motivated learners.

We have adopted the following compromise solution to the question of how frequently to test. In graduate-level courses we give infrequent tests (two or three a semester) but usually have a course project that represents a sizable portion of the grade. In senior courses we use slightly more tests (three or four). In junior courses, despite the great deal of material to be covered, we increase the number to five or six during the semester. In sophomore courses where there is often little new material to learn but students need to become expert at applying it, we have gone as high as two quizzes per week (and no homework). For these courses one quiz per week seems to work well. In section 7.7.1 we noted that mastery learning, which has frequent quizzes, is appropriate for computer programming. If mastery learning is not employed we suggest frequent quizzes, such as one per week. Frequent quizzes ensure that students are practicing the material and are receiving frequent feedback.

What about finals? There are mixed emotions about finals (for example, see Eble, 1988; Lowman, 1995; Svinicki and McKeachie, 2014). Finals require students to review the entire semester and to integrate all the material. They can also be useful for slow learners and for those who initially had an inadequate background since they allow these students to show that they have learned the material. Finals are also useful for assigning the course grade. Unfortunately, they are stressful for students and are almost universally disliked. In addition, feedback to the professor on what students have learned is too late to do any good in the current semester. To the students feedback is almost nonexistent. Most students look only at the grade and do not study their mistakes on the final.

A professor choosing to give a final has several interesting options that can reduce the stress. If other tests have been reasonably frequent during the semester, students can be told that the final can only increase but not decrease their grade. When this is done, it makes sense to tell students their current earned grade and then make the final exam optional. There will also be less cheating on an optional final since the stakes are lower for most students. In PSI and mastery courses an optional final can be used as one way to improve students' final grades with no risk. Another option is to give a required final but tell students that their grades will automatically be the higher of their composite grade for the entire course or their grade on the final. It makes sense to give high grades to students who prove at the end of the semester that they have mastered the material, but having only a final is too stressful. In this way you are also rewarding them for what they know at the end of the term instead of penalizing them for deficiencies they may have had at the start of the semester. Feedback can be made more meaningful by going over the final in a follow-up course the next semester.

Many universities have a scheduled finals period. In a course without a final, this time may be used for other purposes. In a course with projects, the final examination period is an excellent time for student oral reports on projects. This period can also be used for a last hour examination that is not a final. One advantage of using the finals period for an hour examination is that more time is usually allotted for the final, and students taking an hour examination during this period have sufficient time to finish even if they work slowly.

One additional type of quiz is the unannounced, surprise, or "pop" quiz. Some professors like to give several of these during the semester. After answering questions, the professor announces there will be a pop quiz. Once the students' groans subside, a short quiz is administered. Pop quizzes help keep students current and they reward attendance. The major disadvantage is that they increase stress, but this increase in stress can be controlled by:

1. Noting in the syllabus that there will be unannounced quizzes.
2. Making the quizzes a small fraction (2 to 3%) of the course grade.
3. Giving some points for the student's name (i.e., rewarding attendance).
4. Throwing out the lowest quiz grade. This helps students who miss a class that happens to have an unannounced quiz.
5. Making the quizzes short (five to ten minutes).

11.2.2. Coverage on Tests

How do you decide what to put on a test? If objectives have been developed for the course, the decision is relatively simple. The important objectives are tested (Davis, 2009). At what level in Bloom's taxonomy (see Chapter 4) should the test be? If at the higher levels, then the test questions need to be evaluated for appropriateness.

Table 11-1. Example Grid for Test Preparation

Objectives or Topics	Level					
	Knowledge	Compre-hension	Application	Analysis	Synthesis	Evaluation
1	X		X			
2		X		X		
3	X	X			X	
4	No problem for this objective					

An effective method for ensuring that the test covers the objectives appropriately is to develop a grid (Felder and Brent, 2003; Svinicki, 1976) as illustrated in Table 11-1. For each objective or topic, think of a question or problem that allows you to test at appropriate levels of Bloom's taxonomy. It is probably not necessary to have any problems that are solely at the knowledge level since this level is usually included in higher-level problems.

Once the preliminary grid has been developed, you can check it to see if the proposed test satisfies your goals for a particular section of the course. Since not all objectives or topics can be included at all levels of the taxonomy in a single test, you need to make some compromises. Is the coverage of topics on the test a fair representation of the coverage during lectures and of the homework? If not, the exam probably is not a fair test of the course objectives, and students are likely to think it is unfair. Although not all topics can be covered, one should try to have reasonably wide coverage. If a topic is discussed in two separate parts of the course, it might be reasonable to include it in one test and not the other. The levels of the questions also need to be considered. If higher-level activities are important, they need to be included in homework and in tests. Without a conscious effort, it is highly likely that only the three lowest levels will be used since questions at these levels are the easiest to write and grade (Stice, 1976). For the grid shown in Figure 11-1, the instructor has decided not to test for objective 4 or to include any questions at the evaluation level on the test.

Should the test be open book or closed book? The argument in favor of open book tests is that practicing engineers can use any book they want to solve a problem. Open book tests also reduce stress. One argument against them is that too many students use the book as a crutch and try to find the answer in the book instead of by thinking. Another opposing argument involves logic. The practicing engineer argument relies on a false analogy because the purpose of the open book is different: Unlike students, these engineers are not being tested on their knowledge. One problem with closed book tests is that students may be forced to memorize equations they would always look up in practice. Closed book tests may encourage memorization of all content and not just the equations.

Some compromise arrangements are between the extremes of open book and closed book tests. The instructor can prepare a sheet of important equations for students to use during the exam and hand this sheet out to them before the test so that they know what will be available for the test. When the exam is administered, each student receives a clean set of equations. The advantage of this compromise is that the professor has control over the information each student has available during the test. Another compromise is to allow each student to bring a key relations chart (see Section 15.2.1) on one piece of paper or an index card. The advantage of this procedure is that students benefit from preparing the chart because they have to be selective and make choices. Some students will not look at their chart during the test.

11.2.3. Writing Test Problems and Questions

How do you write the problems or questions for tests? What style of questions is appropriate? This section discusses some general rules for writing exams and then explores specific formats for questions.

In writing examination questions, avoid trivial questions even when testing at the knowledge level. Avoid trick questions also since they do not test for the student's understanding and ability in the course. Problems should be as unambiguous as possible unless you are explicitly testing for the ability to do the *define* step of problem solving. To test for clarity have another professor or your TA read the test and outline the solutions. The time required for the exam can be estimated by taking the time you require to solve the problems and multiplying by a factor. We use a factor of 4 for first year students and sophomores, a factor of 3 for juniors, and a factor of 2 for seniors and graduate students. The number of points awarded for each problem should be clearly shown on the test so that students can decide which problem to work on if time is short.

Solve the problems before handing out the test. This aids in grading and helps to prevent the disaster that will occur if an unsolvable problem is on the exam. (If you want the students to perform a degree of freedom analysis to determine if the problem is solvable, then it is reasonable to have an unsolvable problem on the test. However, warn them ahead of time that this may happen; otherwise, they will assume all problems are solvable.)

If tests are returned to students (which is a useful feedback mechanism), then you should assume that files exist on campus for all old exams. Even if you require students to return tests after they have seen their grades, you should assume that at least rudimentary files exist. Since the purpose of a test is to determine how much a student has learned and not who has the best files, you should write new tests. If exams are given frequently, this is a considerable amount of work. Once a large number of questions, particularly of the multiple-choice variety, have accumulated, you can recycle a few questions on each test. Old test questions do make good homework problems, and students appreciate the opportunity to practice on real test problems. Since some students have files, many professors provide files of old tests on the internet so that everyone has equal access to information. Another more drastic solution to the file problem is to periodically revise the curriculum and reorganize all the courses.

Although it may sound contrary to the previous advice, every once in a while a homework problem should be put on a test. This rewards students who have diligently solved problems on their own and is a clear signal to students that they should work on the homework.

How do you generate interesting problems that test for the objectives at the correct level but are not clones of textbook or homework problems? One way is to take an existing problem and do permutations of which variables are dependent and which are independent. Changing the independent variable often changes the solution method remarkably. Brainstorm possible novel problems. Use problems from other textbooks, but if this is done consistently, some students will catch on. Set up an informal network with friends at other universities to share test problems and solutions. As part of their homework assignments have students write test problems. The occasional use of one of these will reward the student who made it up. (In our class on teaching methods the test is based entirely on student-generated questions.) Don't wait until the last minute to start generating problems. It is often productive to generate ideas throughout the semester. Then, the details of the problem and the solution can be worked out when the exam is made up.

Test problems usually fit into one of the following categories: short-answer, long-answer, multiple-choice, true-false, and matching. Since true-false and matching have scant use in engineering, they will not be considered here but are discussed elsewhere (Eble, 1988; Lowman, 1995; Svinicki and McKeachie, 2014).

Short-answer. Short-answer problems include problems requiring identification of a principle, a brief essay, and short problems. In engineering, short problems are the most common and they are effective for the three lower levels of Bloom's taxonomy. As long as complete long problems are also employed, short problems are an excellent way to determine if students have mastered certain principles. These problems are set up so that three to five lines of calculation give the desired answer. The problem is tightly defined so that the student is tested for application to a single principle. Thus, these problems can be very useful for assessment of program outcomes for ABET.

Short-answer problems can also be used to develop students' skills as problem solvers. The problem focuses on one or two stages in the problem-solving strategy. Students can be asked to define the problem clearly but not solve it. Or, they can be given a "solution" to the problem and asked either to check the solution or to generalize it. Students need instruction in doing this type of short answer problem since they always want to calculate.

Long-answer. Long-answer problems include essay and complete long problems. In engineering, complete problems are probably the most common type of test problem. They are necessary to determine if students can find a complete solution. Unfortunately, an exam consisting entirely of a few long problems cannot test for all the objectives covered in the course. Thus, a mix of both long- and short-answer problems is often appropriate. Long-answer problems can also be difficult to score for partial credit (see Section 11.3.1).

To assess for student satisfaction of the ABET professional outcomes (see Section 4.6) an occasional short or long answer essay is required. These essays can be done as take-home assignments. Assessment (and grading) of essays is greatly eased by using rubrics (Walvoord, and Anderson, 2010; see Appendix of Chapter 4).

Multiple-choice. With the regrettable but probably inevitable increase in class size at many engineering schools, multiple-choice examinations will become increasingly popular. They are easy to grade and, if properly constructed, can be as valid as short-answer questions (Kessler, 1988). Unfortunately, properly constructing a classical multiple-choice question is more time-consuming than constructing a short-answer question. Thus, the professor transfers some of her or his time from grading to test construction. This trade makes sense only with large classes. General rules for constructing classical-style multiple-choice questions are given by Eble (1988), Lowman (1995), and Svinicki and McKeachie (2014), while engineering examples are presented by Kessler (1988). The stem, which is the question itself without the choices, should be complete, unambiguous, and understandable without reading the choices. The correct answer and the incorrect answers (the distractors) should be written as parallel as possible. Thus, all possible answers should be grammatically correct and about the same length. There should be no "cues" that allow a good test taker who is unfamiliar with the material to discard any of the distractors or to pick the right answer. Most authors suggest a total of four choices, all of which should appear reasonable. The instruction should ask the student to pick the "best" choice so that arguments with students can be minimized.

In writing a multiple-choice question, it is convenient to start with a short-answer problem. The correct answer is then obvious. The challenge lies in choosing distractors. If a similar short-answer question has been used in the past, look at the students' solutions to find common errors. Then construct the distractors so that the numerical answer follows from these common student mistakes. Most authors suggest that "none of the above" is an improper distractor or answer. Once the distractors have been written, randomly assign the answer and the distractors as *a*, *b*, *c*, and *d*.

When questions have numerical answers, there is a clever alternate type of multiple-choice question (Johnson, 1991). For each question, list ten numbers in numerically increasing order. Tell the students to select the choice nearest to their calculated answer. If the calculated answer is the average of two adjacent choices, tell them to select the higher choice. The effort in writing distractors is thereby reduced. You pick choices over a feasible range at reasonably narrow intervals. This procedure also reduces the probability of a guess being correct. With the usual type of multiple-choice question the student who doesn't get one of the listed answers knows that he or she has made a mistake, but this procedure does not provide this clue. In addition, if you initially make a mistake solving the problem or there is a typographical error in the problem statement, all is not lost. As long as the problem is solvable, one of the choices is correct.

One of the advantages or disadvantages of multiple-choice questions (depending upon your viewpoint) is that there is no partial credit. Students who know how to do the problem but who make an algebraic or numerical error will receive the same credit as students who have no idea how to do the problem. Since numerical and algebraic errors cause loss of all credit, we suggest that multiple-choice questions be used only to replace short-answer questions and not long problems. Both multiple-choice and one long-answer problem can be included on a test. This will significantly reduce the grading without significantly decreasing the validity of the test.

Test stress can be reduced by providing space on the examination for student comments. Tell the students the purpose of this space and explain that the comments will not affect their grades. Then, when you read a comment that says "This problem stinks," you will hopefully realize that the student is just letting off pressure.

11.2.4. Administering the Test

The first part of administering a test occurs the class period before it is given. Discuss the exam with the students (Davis, 2009). Clearly state the content coverage by telling them which book chapters and which lecture periods will be covered. Make the objectives (Section 4.2) for this part of the course available on the web and discuss these objectives in class. Explain the type of test and show a few old problems as examples. Discuss the ground rules, such as staggered seating, closed book or open book, time requirements, and so forth. Particularly for lower-division students, it is helpful to give a few hints on studying and test taking.

Optional help sessions are useful, but first set rules for the session. We hold help sessions in which students must ask questions. When the student questions stop, the help session is over. If a student asks a question that is very similar to a test problem, answer the question in exactly the same manner as you answer other student questions.

McKeachie (1986) suggests making up about 10% extra exams. It is easy for the secretary to miscount or to collate a few exams with blank pages. The extra copies allow you to rectify these problems quickly. Take reasonable precautions to safeguard the test copies, such as locking them up in a briefcase or desk in a locked office.

To students the exam is one of the most important parts of the class, so plan on being there if it is at all possible. If being present is not possible, give the proctors contact information such as your cell phone number. As the professor, only you can answer student questions properly and help students understand what they are supposed to do. In addition, if a student finds a typographical error, only you can make last-minute changes to correct the problem. Professors usually have better control of the class than do TAs.

Come early and have the TAs come early. This gives you time to check the lighting, straighten up the chairs, and start to arrange the students in alternate seats. Plan to distribute the tests as quickly as possible to give everyone equal time. In very large classes put a cover sheet on the exams and tell the students not to open them until given the signal to start. Have them put their names on the test immediately. Then have them count the questions to be sure they have a complete test. About ten minutes into the exam count and record the number of students. If you know all the students in the course, determine if all the students are present and who, if anyone, is missing.

If your school does not have an honor code, it is traditional to proctor the examination, and it is also helpful to have someone present to answer student questions. A circulating proctor can do wonders in reducing the desire students might have to cheat (Lang, 2013). A TA standing discretely in the back of the room can also be a major deterrent. It is much better to prevent cheating than to deal with it after it has occurred (see Chapter 12).

Periodically write on the board the time remaining. Then state, "You have two minutes, please finish your papers." When the time is up, stop the class firmly and collect the papers. It is best to give tests where there is effectively no time limit, but this is often difficult to schedule.

As soon as the examination is over, count the tests. Then check them in against the student roster. It is best to know immediately if a student has not handed in a test or was not present. Students have been known to occasionally complain that their test was lost.

11.3. SCORING

We draw a distinction between scoring tests, which has a feedback function essential for the student's learning, and grading, which is a communication at the end of the semester of how well the student has done in the course. Grading will be discussed in Section 11.6. Unfortunately, both of these activities are often called grading.

11.3.1. Scoring Tests

Extra effort taken while preparing an examination is recovered when the tests are scored. Multiple-choice tests can be machine-scored or with a homemade stencil. In fact, the attractiveness of multiple-choice tests for large classes lies in the ease of scoring.

For other tests an answer sheet and a detailed scoring sheet should be prepared by you as the professor. Evaluation is difficult, and you can do a better job than a TA in preparing both the answer sheet and deciding the breakdown of points. The scoring sheet should be developed for the "standard solution." The TA should be instructed to show you unique solution paths. Occasionally, a student develops a creative solution path but makes a numerical error and gets the wrong answer. To avoid dampening creativity, it is important that you carefully consider these alternate solutions.

Whoever scores the test should do so without looking at the name. Students should receive the score that they earn, not the score that the grader thinks they should earn. Extremely important tests such as qualifying examinations should probably use a code letter for every student instead of a name. Only one person should grade a problem, and this problem should be graded on every test before the person grades a second problem. This procedure helps to ensure that grading is uniform. For a series of short-answer questions it might be feasible and faster to grade the entire sequence on each test paper before proceeding to the next. After one problem has been graded on all tests, review the scoring, particularly of the first few tests that were graded. Be sure that the scoring is uniform.

The best way to score tests for classes that are not huge is to have a "grading party" where you sit down with all the TAs and undergraduate graders and grade all the tests. This procedure allows you to talk to the TAs and graders when they find a test that is challenging to grade. Also, by doing your share of the grading you help develop a team atmosphere. Providing pizza for the "party" always goes over well. With everyone in the same room the grading will be done quickly and, since you will be available to answer questions, accurately. However, if the "party" lasts too long and people become tired they will start to make mistakes even if fueled with pizza and caffeinated beverages. If you cannot get everyone together for a long enough period to grade everything, it is still helpful to sit down with each grader for half an hour while you both grade a reasonable sample of tests. Make sure the scoring sheet is effective for rewarding partial credit and discuss any unusual solutions with the grader. Indicate the type of feedback you want put on the tests.

If you have to delegate the scoring of tests to the TAs and graders it is helpful to do some preparation first. For long problems it is often useful to look at a few sample tests before giving the tests to the grader. The sample may show a common mistake that will require adjustment of the grading scheme, or may indicate a second correct solution path. Give the TA or the grader a reasonable deadline for return of the exams as well as some hints on how to grade this type of test. Tell the TA to bring in any nonstandard solutions so that you can check them over.

We believe in awarding partial credit for long problems. Our reason in favor is that students can often demonstrate understanding of how to solve a problem and not have the correct solution because of a relatively small error in technique, an algebraic error, or a numerical error. On the other hand, since students also need to realize that engineers must be accurate, problems without partial credit can be given as short-answer or multiple-choice questions. Expecting seniors to be more accurate and reducing the amount of partial credit is another approach to encouraging accuracy.

If partial credit is to awarded, develop the scoring sheet for the standard solution. Do this in advance and then adjust it after looking at a few tests. You can determine partial credit by awarding points for parts of the solution that are correct or by subtracting points for parts that are wrong or missing. In long problems these two approaches often result in different scores, and if a scoring sheet is not used will certainly result in different scores. For the highest reliability use a scoring sheet and calculate a score by adding positive items and subtracting negative ones. Discrepancies in the results obtained are a signal that the scoring needs to be reconsidered.

In addition to scoring the exam, provide written feedback and marks on the test or instruct the TA to do so. Correct parts of the test can be indicated quickly with check marks, while incorrect parts can be crossed out. Be sure that there is some mark on each page, including empty pages, so that the student will be sure that every page has been seen (Lang, 2013). This procedure also prevents students from writing on the blank page and then requesting a regrade because the grader "did not see part of my test." Both positive and negative comments should be written on the test. Comments that explicitly correct the student's work are much more useful than writing "wrong" or "incorrect" without explaining why. Positive comments such as "good" or "clever derivation" serve as motivators.

To be effective, feedback must be prompt—Ideally, immediately after the student has finished the test. This procedure is used in some mastery and self-paced classes (see Section 7.6). In large classes it takes longer to grade tests, but there is no excuse for taking a month or longer to return tests. If possible, hand them back the next class period. If not possible, be sure to return them within one week. Tell the TAs in advance which weeks there will be tests so that they can arrange to have sufficient time to grade the exams quickly.

If it is to be useful, students must pay attention to the feedback. There are several methods that can be used to ensure that this happens.

1. Hand back the test and discuss it in class. A variant of this is to have small groups discuss the exam. This procedure is useful since it can reduce student aggression.
2. Before discussing the solution, assign one of the test problems as homework.
3. Give one or more of the problems on a second test.
4. Ask students who obviously do not understand the material to see you privately.
5. Give students who solve the problem on their own after the test but before the solution is posted part credit.

Student scores on exams are private, privileged information. Write the score on the inside or fold the test over when returning the test papers. Alternatively, use a secure procedure such as a learning management system to privately post grades for students.

We have always reported the average test score to the students when we return the tests. Stump et al. (2014) suggest that this practice can foster performance goals or a strategy of doing whatever will earn a high grade instead of focusing on deep learning (see section 15.3.1). As an alternative to reporting the average score, the professor can state what score represents satisfactory progress.

11.3.2. Data Manipulation and Critiquing the Test

After the test, fix any problems that are not quite perfect for later use as homework or for that book you will write someday. Correct any typographical errors on all copies of the test you keep and in your computer files. If some students have misinterpreted the problem, reword it so that this will be less likely to occur in the future. Perhaps one of the misinterpretations will give you an idea for an alternate test problem that can be used next year. Write the idea down and put it into your test file for future use.

It is easy to determine if an exam problem discriminates between students who do well on the test and those who do poorly. Johnson (1988) suggests a simple procedure for doing this. Separate out the tests of the ten (or fifteen in large classes) students with the highest scores on the test and of the ten (or fifteen) students with the lowest scores. For problems where no partial credit is given, let H equal the number of top ten students who got the problem correct, and L equal the number of bottom ten students who got the problem correct.

The test has positive discrimination if $H - L > 0$, and negative discrimination if $H - L < 0$. If a problem has negative discrimination, the better students are having more difficulty. These problems need to be rewritten. The sum of correct scores, $H + L$, can also be looked at. Johnson (1988) suggests that this figure should be between 7 and 17. We think this range is too low and prefer from 12 to 18 and up to 20 in mastery courses. If partial credit is given, the discrimination of each item can be determined by looking at the sum of scores for the ten best and for the ten worst students.

If the test scores are quite low and you want to use an absolute standard grading scheme at the end of the term (see Section 11.5.2), some *scaling* of the test scores may be helpful (Ieta et al., 2010). The easiest scaling procedure is to add the same number of points to every students score. This scheme is considered fair by the students, but can give scores greater than 100 if one tries to move the average test score up significantly. A variant is to increase everyone's scores by the same amount, except scores that would be greater than 100 are capped at 100 (Why is a score greater than 100 considered a problem?). This procedure will appear unfair to the better students who receive fewer additional points. On the other hand, normalization of the scores by multiplying every score by 100/(maximum test score) makes the highest score a 100, but gives lower increments to the poorer students. We guarantee they will howl. Our suggestion is to scale by the same amount and don't worry if some scores are greater than 100. Next time, try to write a test that can be solved in less time.

In large classes (more than 20 students), standard scores may be useful for comparing student scores on different tests and for deciding final grades (Cheshier, 1975). Calculate the mean test score $\bar{x}$ (N = number of students, x_i = test score),

$$\bar{x} = \frac{\Sigma x_i}{N} \tag{1}$$

and the standard deviation s,

$$s = \frac{1}{N}\sqrt{N\,\Sigma(x_i^2) - (\Sigma x_i)^2} \tag{2}$$

Then the z_i score is

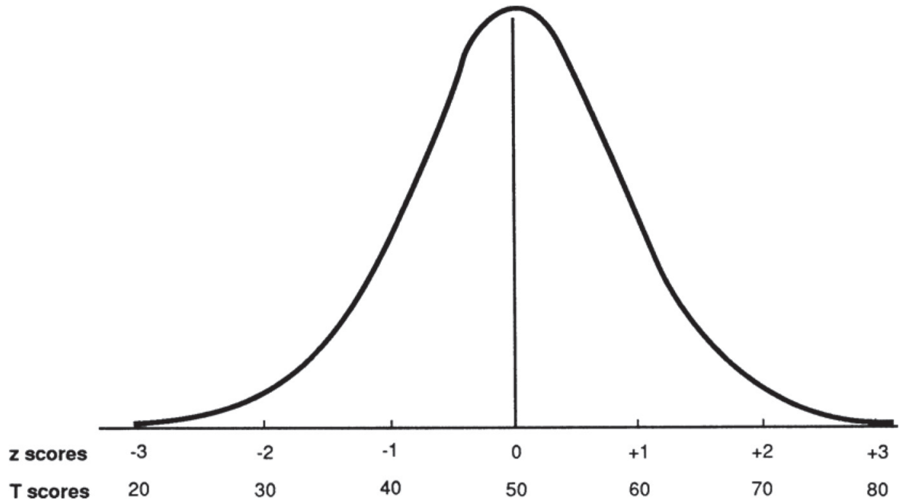
$$z_i = \frac{x_i - \bar{x}}{s} \tag{3}$$

The z_i score is a normalized score for each student that has a mean of zero and a standard deviation of 1. The z scores can be converted to T scores where the T score has a mean of 50 and a standard deviation of 10.

$$T_i = 10\,z_i + 50 \tag{4}$$

The standardized scores are easily calculated with a calculator or computer. If the class follows a normal distribution, which is unusual, then the z and T scores are shown in Figure

Figure 11-1. Distribution of *T* and *z* Scores for Normal Distribution of Scores



11-2. The *z* or *T* scores for each student can be averaged and then compared to other students' scores. Averaging raw scores for each student is not statistically valid since both the means and the standard deviations vary from test to test. A very simple example may help to clarify the use of standard scores. Consider Debbie who has the following scores on three tests: 60 (class average = 60, s = 15), 40 (class average 30, s = 10), and 80 (class average 85, s = 5). Her corresponding *z* scores are 0, +1, and -1, while the *T* scores are 50, 60, and 40. Compared to the class, her lowest grade is the last one which looks highest on the basis of raw scores.

There can be problems with the use of standard scores. In small classes they are not statistically valid and should not be used. Scores of 100 or 0 do not remain 100 or 0 when translated to T scores. Extreme scores can become negative or greater than 100. Thus, *T* scores can be misleading for these extreme scores, and the extreme scores can skew the entire distribution (see the Appendix of this chapter for an example). Finally, the usual interpretation of the meaning of one standard deviation is valid only for normal distributions. *T* and *z* scores can still be used for distributions that are not normal but must be interpreted with care. Cheshier (1975) highly recommends the use of standard scores, but McKeachie (1986) does not think they are worth the effort. We agree with McKeachie, but you get to choose. If you do use standard scores, it is important to spend a few minutes explaining them to the class. Of course, in a class which uses statistics or discusses error analysis, the use of standard scores can be a useful part of the course objectives.

11.3.3. Regrades

Allow regrades! If handled properly, they make you seem fair, reduce student aggression, force some students to reexamine the test problems, and do not take much time.

In small classes regrades can be handled informally by discussions between the students and the professor. Large classes require a more formal procedure (Wankat, 1983). Regardless of the method used, the regrade procedure should be discussed with the class when the first test is returned. Students are ready to listen at that time.

If the scoring error the student wishes to correct is the incorrect addition of points, then we encourage the student to see the professor immediately following the class. In large classes there will be several students clustered around the professor at this time. Thus, it is a good idea to collect the tests to allow time to check the addition.

The second type of scoring error is a mistake in the scoring where the student believes he or she deserves more points. In large classes we require a written regrade request. Students are told to make no additional marks on their tests. On a separate sheet of paper the student is asked to logically explain why he or she deserves more points. The emphasis here is on "logical," not the plea "I deserve more points." For example, a student who uses a different solution path than the standard solution may claim that his or her path was correct but that the answer was incorrect because of an algebraic or numerical error. The student is told to rework the problem by using his or her path and show that the correct solution is obtained. Based on this type of argument, we have occasionally given a student a large increase in a test score. Quite often while trying this procedure the student finds that the path really does not work, and no regrade is requested.

Students are told that there may be an increase, no change, or a decrease in their test score. We ask for the entire test back but seldom regrade the entire exam. The advantage of getting the entire test back is that the professor can tell if extra pages have been inserted since the original pages will have additional staple holes in them. Some professors regrade the entire test (Evett, 1980), but this policy seems designed to prevent students from asking for regrades instead of being for the educational benefit of the student.

Give students a deadline (one week is sufficient) for regrade requests. This prevents last minute "grade grubbing" by students. Once the regrade requests have all been collected, sit down with the TA and discuss them so as to ensure that grading is uniform. It is poor policy to give complainers higher scores just because they complain. Chronic complainers can be controlled if the professor carefully checks the TA's scoring of their tests before returning the tests.

11.4. HOMEWORK

What is the purpose of assigning homework? While doing homework the students are active and have a chance to practice the skills being taught in the course. A modest amount of drill can be useful since students learn how to perform certain operations quickly and accurately. Of course, the value of this practice depends on the timeliness of the feedback about the homework. To be effective, this feedback should consist of both positive and negative comments. Homework problems also provide students with a fair chance for success, yet some should also be challenging since both success and curiosity are motivating. Homework is beneficial for student grades since there is a strong correlation between effort on the homework and test scores (Yokomoto and Ware, 1991; Wankat, 2001). The use of study groups should be encouraged since these groups are beneficial for extroverts and field-sensitive students. Homework groups are often not as effective as they could be. An analysis of homework teams is shown in Table 11-2. Knowing that the performance of their group could improve may encourage some groups to do better.

What percentage of the course grade should be based on the homework? If it is low, some students will tend to ignore the homework unless a special effort is made to illustrate the cor-

Table 11-2. Hierarchy of Homework Teams (Courtesy of Susan Montgomery)

Dysfunctional	One or two people do all the work, others pretend to understand or are just totally absent- Really? Unacceptable.
Thinks It's About Getting the Homework Done	Everybody is responsible for one problem, explains it to everyone. Efficient, but everyone understands only 25% of the material.
Thinks They're a Good Homework Group	Everybody works on all problems together - as soon as one person figures it out, they tell everybody else how to do it, depriving them of the opportunity to work it out on their own.
Actual Good Homework Group	Everybody makes a genuine effort to work out all the problems, comes prepared to the meeting, a great discussion ensues about how each person did the problem, what to watch out for, lessons learned, someone goes to office hours, comes back to final meeting and all issues are resolved, and learning happens.
Beyond a Homework Group: The Study Group	Focus is beyond getting the homework done, on understanding concepts. In addition to above homework discussion they also review class notes, ask "what if?" questions, and realize that this is for real.

relation between homework effort and test results. If the percentage is high, many students will be encouraged to copy others' work, to find solution manuals online, or to cheat in other ways. A reasonable compromise seems to be 10 to 15%. This is low enough that you can encourage students to work in groups, but require each to hand in an individual homework paper. Students who extensively copy homework are more likely to fail the course even if there is no penalty for copying (Lang, 2013).

Late submissions can be a difficulty. In industry, late work is accepted grudgingly and does not earn promotions or handsome raises. We suggest telling students this and then following industrial practice. Accept late work grudgingly and take off some percentage based on how late it is. We accept no homework after the solution has been posted. Our policy is considered fairly lenient by most professors who believe that students should meet deadlines. Ask if your department has a policy, and if the department does, follow it. Policies that seem a bit harsh can be softened by dropping the lowest one or two homework scores.

11.4.1. Homework Problems

Homework problems should cover all levels of Bloom's taxonomy and all levels of the problem-solving taxonomy (see Chapters 4 and 5). A gradation of problems, from easy to difficult, to cover many different aspects should be used. Some of the homework problems should be easier, some should be harder, and some should be at the same level of difficulty as the tests. Homework problems can focus on various aspects of the problem-solving strategy such as

Table 11-3. Range of Homework Problems (Adapted from Yokomoto, 1988)

Concrete	Abstract
Simple	Complex
Linear solution	Simultaneous solution
Linear solution	Trial-and-error
Short	Long
Answer given	Answer not given
Very clearly defined	Slightly ambiguous
Data given	Need literature data
Self-Contained	Build on previous material
Forward solution	Backward solution
Hand calculation	Computer
Written	Visual
Logical	Brainstorm
Numerical	Symbolic

defining the problem, brainstorming possible solutions, and checking with an independent solution method. Other dimensions that need to be considered are discussed by Yokomoto (1988) and are shown in Table 11-3. Except in programming courses, computer problems should emphasize the use of software tools.

How often should homework be assigned and how many problems should be given? In the US students need an activity for every week whether it is a test, homework, or a project. These activities should be due on different days. By working around your test schedule, you can determine when homework needs to be done. If you have a large number of tests or quizzes ask students to do less homework. The number of problems obviously depends upon length. Following the need for a range of problems as shown in Table 11-2, the professor can make some assignments consisting of five small problems and other assignments consisting of a single long problem.

However, assigning a significant amount of homework involves finding or developing homework problems and solutions, scoring the homework and providing adequate feedback. Once upon a time, professors could use the problems from the textbook and the solutions from the solution manual with reasonable assurance that students did not have access to the solutions. This is no longer true as many solution manuals are readily available on the Internet. However, the problems in the textbook can still be used in controlled circumstances such as for examples in lecture, in recitation for group problem solving, and as "do-it-yourself" problems that the students know will not be handed in or graded. The textbook problems are also useful for developing similar problems with different numbers. If the solution is done in a spreadsheet, developing new problems every year becomes fairly easy. An alternative is to use individualized problems generated by a company such as Sapling Learning (http://www2.saplinglearning.com/; Liberatore, 2011).

Scoring can be a particularly significant time sink if the professor does not have assistance. One solution is to score only selected problems. Tell the students ahead of time that not all problems will be scored. If the problems to be scored are randomly selected, the final homework grade will be proportional to the total amount of homework the student does during the semester. An alternative that the students like is to score two problems on each assignment—one problem that the student chooses and one problem selected by the professor. Students need to have solutions available on the learning management system for problems which are not scored.

With a large number of quizzes it is not necessary to have students hand in homework. They will soon come to believe the professor when he or she tells them that students who do the homework do better on the quizzes. If you have taught the course before show a plot of homework scores versus exam scores (Wankat, 1999). Occasionally using a homework problem on a quiz also reinforces the importance of homework. Once again, solutions to the homework need to be available.

11.4.2. Other Types of Assignments

Reading assignments pose somewhat different problems. Students will read the assignments if they see that reading leads to success in homework and tests. Your task is to ensure that the reading contributes directly to the student's success. And if the reading does not help the student achieve success, why is it assigned? Be sure to select a good textbook (see Section 4.5) or other readings. Skip certain material in lecture, but make it clear to the students that it is material they are expected to learn from the readings. Refer to this material in the lecture, but do not cover it. Ask questions in class or online before class (give a few points for correct responses) based on the readings. Reiterate to the class that it is important material. Then assign homework based on the material and include test problems based on it. It doesn't hurt if one of the homework problems is a clone of an example in the textbook.

A glance at ABET criterion 3 in Table 4-4 shows that many of the criteria will require assignments that are different from problems. Teaching design and lab were discussed in Chapter 9. Obviously, to assess writing you need to have the students write. Writing and oral presentations are normally assessed in laboratory and design courses, but we feel this is not sufficient. Students need to have written assignments and oral presentations every semester or at least every year. How do you do this in a large class? Short specific written assignments are easy to grade with a rubric (see Chapter 4 appendix) *and* allow you to simultaneously assess one of the other ABET professional outcomes. For example, "Describe how technology xyz will affect people in the United States" is a generic assignment suitable for any class that will allow you to assess both ABET criteria 3g (communication) and 3h (impact of engineering solutions). We have found that it is necessary to be very prescriptive about length, font, margins, and so forth; otherwise, students will game the system to reduce the amount they have to write. The following instructions are from a junior level engineering course:

> What needs to be turned in is a typed (word processed) report written so that a person who was not familiar with the assignment could understand it. Thus, there should be an introductory sentence or paragraph explaining your purpose in this short essay. Then write one paragraph for each

step in the IDOL format. Minimum length is one page plus one line on the second page, Times New Roman 12 point type, line spacing of Multiple at 1.15, normal one-inch margins, extra line space between paragraphs, and no cover page. Maximum length is two pages.

The IDOL format is a method of logically arguing an issue using a claim-data-warrant model. Most engineering students have had little experience writing essays that back up their argument with data and logic. The acronym IDOL (Dillon and Jenkins, 2013, p. 82) is:

I Identify a specific claim

D Develop an argument to support your claim

O Offer an example(s) that supports your argument

L Link the example(s) to the claim

Setting a maximum length in the assignment protects the students and you from unnecessarily long reports.

Oral presentations can take up a large amount of class time, and, frankly, the students in the audience tend to find them boring. A solution that works well in classes with up to about 30 students is to have the students present an *elevator speech* to you in your office. The elevator speech is a planned, but spontaneous, presentation typically ranging from 45 seconds to 2 minutes that tries to convince the listener (a captive audience in an elevator) to do something. We usually have the student ask for an interview for an internship or a job after graduation. After the presentation, we hold a structured interview with the student to get to know them better and to further explore the student's satisfaction of ABET criteria.

11.5. PROJECTS

Design and laboratory reports can be considered special types of project reports, but since they were discussed in Chapter 9, they will not be considered further here. Open ended projects where the topic is selected by the student are most common in smaller classes such as senior electives and graduate courses. If long projects are used with first-year students the students will need less choice in selection of topics and they will need frequent intermediate due dates to control procrastination. Projects can fulfill educational objectives that are difficult to fulfill with lectures and tests. Projects allow students to explore in depth topics of their choice, thereby giving students some control over their education that is often missing from other courses. Consequently, students sometimes become very strongly motivated and continue the project long after the class is over. Projects also provide an opportunity for students to work on communication skills through written and oral progress and final reports. In the ideal case, through the project the professor empowers students to work on areas in which they are intensely interested, and the professor encourages the student to obtain a meaningful result. Our experience in requiring graduate students to do projects is that approximately 20% comes close to this ideal.

Projects must have a deliverable. In a library research project the deliverable is a paper. In engineering it is often preferable to require the student to produce "something" such as a computer program, an integrated circuit, a teaching module, a laboratory experiment, a novel solution to a mathematical problem, and so forth. Then the deliverables are a short report describing the something in addition to that something. The more choices the student has on what to deliver, the more likely he or she is to become excited about the project.

Students naturally want to know what the professor expects. Explaining what is desired (i.e., the objectives for the project) can be surprisingly difficult. However, at some point the professor does decide what he or she wants and grades accordingly. Waiting until the projects are graded to decide what one wants leaves the professor open to student complaints. You need to explain what it is that you really want. If you can't, then analyze the projects from the last time you taught the course to determine what you wanted when you graded them.

How big should a project be? If it is only 5% of the grade, students will treat it as a homework assignment. If it is 50% of the grade, students will feel very anxious about it. Projects that are about 25% of the grade have worked well for us.

Procrastination is the biggest problem with student projects. To limit but not eliminate procrastination, set up a series of deadlines. Introduce the project in lecture relatively early in the semester. Describe the project and the evaluation procedure as clearly as possible. List the dates of all intermediate and final deadlines. In a small class, both written and oral progress reports are useful since they allow for early feedback and make students do at least some work throughout the semester. Individual meetings with each student or student team can also help prevent procrastination.

Evaluation of projects is time-consuming, which is one reason they are most commonly used in small classes. If communication skills are included in course objectives, then projects should be evaluated on organization and writing ability. Professors who are very serious about improving writing should have students turn in full, polished drafts of the report, correct about a third of the report and have the student correct the entire report before it is evaluated for a grade. The written report should also be graded for content, including correctness, depth, and creativity. Although projects are usually turned in late in the semester, many students seriously study the feedback because they have become involved with the material. The best feedback method for oral reports is a video of the student presentations (Section 8.2.5). An alternative that the students appreciate is a poster session with invitations sent to local alumni and high schools. Since the project represents a sizable portion of the course grade, instructors should use their discretion in accepting late reports.

11.6. GRADING

The best advice we can give before a professor decides on the final course grades is to go into an empty room and repeat out loud, "I can't satisfy everyone. I can't satisfy everyone. I can't satisfy everyone." This will help create the proper frame of mind for awarding final course grades. The second thing to do is to realize that grades also will not be totally logical.

11.6.1. Purpose of Grades

There are very diverse views in the literature about the purposes and suitability of the typical grading methods used in colleges. These views range from grades being indispensable to grades should be abolished. The writers who defend grades, at least moderately, include

McKeachie (1976, 1986), Johnson (1988), and Lowman (1995). The purposes they note for grades include:

1. Reward or penalty for student accomplishment.
2. Communication to others about what the student has accomplished.
3. Predictor of future performance.

Grades certainly do serve as rewards or penalties, but for feedback purposes they come much too late in the semester to provide any motivation. As rewards, grades are often used to determine who will receive honors, scholarships, and so forth. As penalties, they are used to place students on probation and to drop students.

Using grades as a communication tool is often confusing since there is no generally agreed-upon definition of what a grade means. However, some communication exists since there is general agreement that an A or B means the student has learned more than a student who receives a D or F.

Grades are also used as predictors. Students use grades as predictors of how well they will do in the rest of their college careers, and in this sense good grades may motivate a student to continue. Poor grades in the first year may convince students that they need to change their ways because engineering has proven to be much more difficult than their high schools. Professors also use grades to predict who will do well in later courses and who might do well in graduate school. Since grades are reasonably good at predicting grades in future courses (Stice, 1979), this use of grades is somewhat reasonable. Even in this case grades can be misused since they do not predict who will be good at research, which is a major part of many graduate school programs.

The most controversial use of grades is as predictors of success in life after school. Many employers use grades as part of their selection procedures. Many, but not all, studies agree that there is little correlation between grades and success after school (Eble, 1988; Kuh et al., 1991; Milton et al., 1986; Stice, 1979). This is true regardless of how one defines success. "The only factor predictive of adult success—however defined, and including post-college income—is participation in out-of-class activities." (Kuh et al., 1991, p. 9) What this means is that engineers who graduate are good enough in whatever it is that grades are measuring to be a success, and that other variables become important. These other variables can include drive, motivation, inherited wealth, common sense, communication skills, interpersonal skills, leadership, who the person knows, and luck. Out-of-class activities can help students hone their leadership and interpersonal skills (Wankat and Oreovicz, 2002). The supporters of grades note that since grades are part of the selection criteria, one cannot expect them to be a major predictor of success since the sample is already fairly homogeneous (McKeachie, 1986). Unfortunately, this argument ignores the actions of companies that arbitrarily chose a 3.0/4.0 or 3.5/4.0 as a cutoff for hiring. We tell students with lower grades to highlight other accomplishments such as leadership in student groups, earning the majority of money needed to pay for school and engineering or related experience. Bowen and Bok (1998) are the exception who found a strong correlation between rank in class and success after college.

11.6.2. Grading Methods

Some intelligent and thoughtful people argue that one should select a grading method that subverts the grading system (Eble, 1988; Elbow, 1986). Mastery learning is an example (see Section

7.7). We will assume that, being new to teaching, you are not ready or willing to subvert the system (yet). Thus, the remainder of this chapter will be on grading hints and methods.

Regardless of the grading method used, the more scores you have, the easier it is to give grades. When there are many scores, and the students know what these scores indicate, there are fewer conflicts with students when grades are awarded. If a student complains about a grade, listen to what he or she has to say. But unless a grading error has been made, it is unwise to change grades. Once a grade is changed, the word gets around and many students want their grades changed.

Students who are unhappy about test scores or their final course grade will often ask about doing extra credit. Ideally, this will have been covered in the syllabus (see Section 3.4). If it is covered in the syllabus refer the student to the syllabus and follow your rules. In our opinion extra credit should not be available after grades are posted because most students in the class would not have an opportunity to do extra credit at this time.

One of the difficulties with grading is the same set of scores can be used to justify a very large number of different grade distributions. This phenomenon is illustrated in the Appendix to Chapter 11 (Stice, 1994; Wankat and Stice, 1999).

The most appealing grading method uses an absolute standard. Although appealing, absolute standards are difficult to administer because you will have to write every test to appropriately measure learning. However, if you are willing to bend the rules a bit, modified absolute standard grading is quite workable. If you are using a 90-80-70-60 scale and you write a test with a high grade of 83, adjust all grades upward by at least 7 points. Then the high grade on this test is an A on the absolute scale. Since homework and project grades tend to be higher, they will bring the overall grades into the desired level. In the syllabus list the 90-80-70-60 scale as guaranteed, but note that you reserve the right to lower the cutoffs. Then absolute standard grading can often be combined with natural gaps. This procedure is illustrated in Table 11-A4 in this chapter's appendix.

Contract or mastery grading (Section 7.7) is another way to use a standard, but this method has its detractors since the grade no longer means what most people think it means (communication), and the grade is no longer a good predictor of grades in a "standard" class. However, Eble (1988), who is not fond of grading, states that the predictive capabilities of grades should not be taken too seriously.

Travers (1950) originally suggested a standard grading scheme that has been echoed by McKeachie (1986). The major and minor objectives of the course are clearly defined. Then the grade is a communication to the student and to others of what fraction of the course objectives has been achieved. The meaning of the grades can be defined in a manner similar to the following:

A: achieved all major and minor objectives
A-: achieved all major and most minor objectives
B+: achieved most major and most minor objectives
B: achieved most major objectives and many minor objectives
B-: achieved most major objectives and some minor objectives
C: minimally acceptable performance
D: student is not prepared for advanced work requiring this material
F: failed

Even with a system like this the professor needs to decide if the student meets an objective, and subjective decisions will have to be made. Normative grading, commonly known as grading on a curve, is often used because the professor does not have to develop and correctly test for absolute standards. Instead, students are compared to each other and the grade curve is broken up into A, B, C, D, and F. This has the unhealthy effect of increasing competition. In addition, a student performance which earns an A in one class may earn a C in another class merely because student competition is better. Because of this effect of class quality, a professor should never force grades into predetermined percentages.

Cheshier (1975) suggests using T scores with the following grading scale for a class of average students: A $\geq$ 63> B $\geq$ 53 > C $\geq$ 43 > D $\geq$ 33 > F where the grades listed are the T scores for each student. If the average raw score is 70 and the standard deviation s = 10, this scale in terms of raw scores is: A $\geq$ 83> B $\geq$ 73 > C $\geq$ 63 > D $\geq$ 53 > F, which means the average student earns a C. For a class of exceptional students he suggests the following grade distribution of T scores: A $\geq$ 57> B $\geq$ 47 > C $\geq$ 37 > D $\geq$ 27 > F. Since the average student in the class has T = 50, the average student earns a B. Of course, there is a subjective judgment, probably based on comparison with previous classes, of whether this is a class of exceptional, average or below average students. The fallacy with T scores is that engineering classes at the junior, senior, and graduate school levels certainly do not follow a normal distribution. If the entering first-year students followed a normal distribution, which could be approximately true at a school with open admission, after the bottom portion has been pruned in the first two years what is left is not a normal distribution. Forcing the upper division classes to fit a T scale will be a disservice to the students (see the chapter appendix for an example).

Many professors are unwilling to use straight scales because their test averages are uniformly too low. A logical solution would be to write more reasonable tests next semester, but what do you do this semester? One procedure is to list all the students' total scores or average scores for the semester. Then decide first where the average grade in the course should be. Many professors believe that the average grade in upper-division courses should be higher than in freshmen courses since the poorest students have dropped or transferred out of engineering. Thus the average student in an upper division course might receive a B+, a B, or a B-. Then look at the distribution and decide upon cutoff points. One method for assigning the cut point for F's first determines the score of a good but not exceptionally brilliant student (usually the second or third best student in the class). Any student who receives less than half this number of points fails the course. The percentages of these students will be less than 50%, and they would fail if straight scales were used. If no one is that low, then everyone passes. With the grade of the average student chosen and the F–D boundary chosen, the other grades can be selected. It is convenient to look for natural gaps in the grade distribution and if they fit put the A–B and/or B–C boundaries there. Natural gaps often mean there is a qualitative difference in student understanding (Svinicki, 1998), and students complain less when there is a large gap between their score and the scores of students with higher grades. Once the tentative borders have been drawn, look at the grades that are on the edges. Should they be moved up or down? Many professors prefer to give students the benefit of a doubt if their scores have been increasing throughout the semester. This can also be accomplished by giving greater weight to later tests or by substituting the grade on the portions of the final exam that cover the same material for the lowest test score if this will raise the student's total score (Vaden-Goad, 2009). The grade replacement procedure gives students hope that one bad test grade will not eliminate their chances of passing the course.

If a plus/minus system is used only a few of the grade boundaries will be at natural gaps; however, because the difference between an A- and a B+ is much smaller than between an A and a B, students tend to complain less. Try to apply wisdom at the boundaries. We have seldom been wrong when we have found reasons to be generous.

11.7. GRADE SCALES

In the past, most universities used some form of a straight 4 point scale where an A = 4 points, B = 3 points, C = 2 points, D = 1 point and F = 0. The professor could inform the student that she really earned a B+, but it is recorded as a B. The grade point average (GPA) for this straight scale and plus-minus scales is easily calculated as,

$$GPA = \frac{\Sigma\,(Credits\ course\ i)(Grade\ Points\ course\ i)}{\Sigma\,(Credits\ course\ i)} \tag{5}$$

Many universities require a 2.0 GPA to graduate although a grade of D will usually count for graduation. Key courses in a major may use a C as the minimum grade to continue. Transfer credit from other universities usually requires a C. The difficulty with this scale from the point of view of the professor is there is a big difference between each grade. Students a few points apart can receive different grades and the difference in the grades is much greater than the difference in the number of points or in the amount the students learned.

A change that many universities have instituted is to keep the 4.0 scale, but make it a plus-minus ($\pm$) scale. Now the grades are usually A+ = 4.0, A = 4.0, A- = 3.67, B+ = 3.33, B = 3.0, B- = 2.67, C+ = 2.33, C = 2.0, C- = 1.67, D+ = 1.33, D = 1.0, D- = 0.67, and E or F = 0. There usually is no F+ grade. Although the grades professors award to students are not this accurate (see the chapter appendix), this scale has eased a professor's burden. With the straight A-B-C-D-F scale the difference between an A and a B is really important to students. With the $\pm$ scale the difference between an A- and a B+ is not nearly as critical.

The $\pm$ scale has actually damped grade inflation a bit, and students are not happy. With the straight scale, students could graduate with very high GPAs (3.90 to 4.0) despite having a number of A- grades. With the $\pm$ scale the A- grades can really hurt a student trying for a high GPA for medical school or other pursuits. What really gripes the students is that an A+, which should, in their opinion, balance an A-, does not. Students believe that in a fair scale an A+ would be worth 4.33 points. Of course, if a university did that it would have a 4.33 scale, not a 4.0 scale.

Students in the C–B range realize that their plus and minus grades probably balance each other, but there are unexpected difficulties for these students also. In a critical core course a C- may no longer be good enough to continue taking courses in the program. The student may be set back a semester or a year, which can be quite expensive. Secondly, if the student takes a course at another institution and wants to transfer the credit to his university, a C- grade is no longer good enough. More money and time are lost.

A suggestion for the A+ dilemma: Cap the student's overall GPA at a 4.0, but if the GPA is less than a 4.0 count an A+ as 4.33 points. Then the grading system will remain a 4.0 system, and plus grades will balance minus grades. Students will be much more likely to believe the university's system is fair. Of course, they will continue to complain about grades received from professors who rate their merits lower than the students rate their own merits.

11.8. CHAPTER COMMENTS

Much more could be said about testing. Tests can be analyzed for validity and reliability by statistical methods. Multiple-choice tests in particular are easy to analyze. We do not think that this type of analysis is particularly valuable in engineering education and doubt that many engineering educators would use these procedures. In any case, most large universities have a testing service that machine-scores multiple-choice tests and calculates the appropriate statistics.

Students usually consider exams to be the most important part of a course since they are the main determiner of their grades. Professors can lament the students' values, but these values are difficult to change. Complaints about tests can be decreased by making them as fair as possible and by having enough tests so that one test will not completely determine a student's grade. Because they consider exams to be so crucial, some students will be tempted to cheat, and cheating is another fact of life that must be faced (see Chapter 12).

HOMEWORK

1. Assume you will write a test for this chapter.
   a. Develop a test grid to decide on the coverage of the test.
   b. Write at least two long-answer questions, two short-answer questions, and two multiple-choice questions for the test.
   c. Select the questions for the test so that it can be given in a regular fifty-minute class.
   d. Write the solutions and the grading scheme for this test.
2. Do a project on teaching engineering material. The project must involve both content (engineering subject matter) and teaching method. You must have a deliverable such as a video, CAI, a self-paced module, a laboratory experiment, a NSF proposal for curriculum development, a student handbook for commercial software, or course demonstrations.

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APPENDIX. COMPUTATION OF GRADES FOR DIFFERENT SYSTEMS.

The numbers are slightly different, but the procedure is the same as used by Stice (1994) and discussed by Wankat and Stice (1999). Determine the grades for the distribution in Table 11A-1.

Table 11A-1. Percentages Calculated from Raw Scores for 37 Students in an Engineering Course (Maximum Number of Points = 600)

90.0	84.6	78.0	69.4	61.3	
89.7	84.6	76.4	69.4	59.5	
89.7	81.6	76.4	66.7	59.2	
89.3	81.6	76.4	65.8	58.8	
86.6	80.7	76.4	65.8	18.7	37 students
86.6	80.7	76.4	61.3	73.93	Avg. 37 students
86.6	78.6	73.5	61.3	75.47	Avg. top 36 students
84.6	78.6	69.4	61.3		

Table 11A-2. Raw Scores and Grades for Straight Criterion Grading with 90-80-70-60 Scale

90.0 A	84.6 B	78.0 C	69.4 D	61.3 D
89.7 B	84.6 B	76.4 C	69.4 D	59.5 F
89.7 B	81.6 B	76.4 C	66.7 D	59.2 F
89.3 B	81.6 B	76.4 C	65.8 D	58.8 F
86.6 B	80.7 B	76.4 C	65.8 D	18.7 F
86.6 B	80.7 B	76.4 C	61.3 D	
86.6 B	78.6 C	73.5 C	61.3 D	
84.6 B	78.6 C	69.4 D	61.3 D	

Table 11A-3. Raw Scores and Grades for Straight Criterion Grading with 85-75-65-55 Scale

90.0 A	84.6 B	78.0 B	69.4 C	61.3 D
89.7 A	84.6 B	76.4 B	69.4 C	59.5 D
89.7 A	81.6 B	76.4 B	66.7 C	59.2 D
89.3 A	81.6 B	76.4 B	65.8 C	58.8 D
86.6 A	80.7 B	76.4 B	65.8 C	18.7 F
86.6 A	80.7 B	76.4 B	61.3 D	
86.6 A	78.6 B	73.5 C	61.3 D	
84.6 B	78.6 B	69.4 C	61.3 D	

Of course, we could look at 80-70-60-50 or other criterion distribution.

If we arbitrarily define a break as 2.0 points or greater, we observe a break of 2.7 points between 89.3 and 86.6, another break (2.0 points) between 86.6 and 84.6, a third break (3.0 points) between 84.6 and 81.6 points, a fourth break (2.1 points) between 80.7 and 78.6 points, a fifth break (2.9 points) between 76.4 and 73.5 points, a sixth break (4.1 points) between 73.5 and 69.4 points, a seventh break (2.7 points) between 69.4 and 66.7 points, an eighth break (4.5 points) between 65.8 and 61.3 points, and a large last break (40.1 points) between 58.8 and 18.7 points.

Table 11A-4. Raw Scores and Grades Combining 90-80-70-60 Scale with Break Points

90.0 A	84.6 B	78.0 C	69.4 D	61.3 D
89.7 A	84.6 B	76.4 C	69.4 D	59.5 D
89.7 A	81.6 B	76.4 C	66.7 D	59.2 D
89.3 A	81.6 B	76.4 C	65.8 D	58.8 D
86.6 B	80.7 B	76.4 C	65.8 D	18.7 F
86.6 B	80.7 B	76.4 C	61.3 D	
86.6 B	78.6 C	73.5 C	61.3 D	
84.6 B	78.6 C	69.4 D	61.3 D	

Often when professors use this method the scores above 90 are guaranteed to be an A, above 80 are guaranteed to be a B or better, and so forth. This is the grading scheme we prefer. This example is remarkable for how close the breaks are to the 90-80-70-60 scale. Often there is more variation.

Table 11A-5. Raw Scores and Grades Combining an 80-70-60-50 Scale with Break Points

90.0 A	84.6 A	78.0 B	69.4 C	61.3 C
89.7 A	84.6 A	76.4 B	69.4 C	59.5 C
89.7 A	81.6 A	76.4 B	66.7 C	59.2 C
89.3 A	81.6 A	76.4 B	65.8 C	58.8 C
86.6 A	80.7 A	76.4 B	65.8 C	18.7 F
86.6 A	80.7 A	76.4 B	61.3 C	
86.6 A	78.6 B	73.5 B	61.3 C	
84.6 A	78.6 B	69.4 C	61.3 C	

This result shows an increased number of Cs because the break is quite a distance below the 60% C-D border.

Table 11A-6. Raw Scores and Grades with an 85-75-65-55 Scale and Larger Breaks, Arbitrarily Set ≥ 3 (Use the 3.0, 4.1, 4.5, and 40.1 Breaks)

90.0 A	84.6 A	78.0 B	69.4 C	61.3 D
89.7 A	84.6 A	76.4 B	69.4 C	59.5 D
89.7 A	81.6 B	76.4 B	66.7 C	59.2 D
89.3 A	81.6 B	76.4 B	65.8 C	58.8 D
86.6 A	80.7 B	76.4 B	65.8 C	18.7 F
86.6 A	80.7 B	76.4 B	61.3 D	
86.6 A	78.6 B	73.5 B	61.3 D	
84.6 A	78.6 B	69.4 C	61.3 D	

Even though the distribution is not normal and T scores are not valid, we can calculate them.

Table 11A-7. Raw Scores, T Scores and Grades with N = 37 and Use T Score Grades for a Class of Average Students with the Following Scale for T Scores: A ≥ 63> B ≥ 53 > C ≥ 43 > D ≥ 33 >F (Chesier, 1975)

90.0 62 B	84.6 58 B	78.0 53 B	69.4 47 C	61.3 41 D
89.7 62 B	84.6 58 B	76.4 52 B	69.4 47 C	59.5 39 D
89.7 62 B	81.6 55 B	76.4 52 B	66.7 45 C	59.2 39 D
89.3 61 B	81.6 55 B	76.4 52 B	65.8 44 C	58.8 30 D
86.6 59 B	80.7 55 B	76.4 52 B	65.8 44 C	18.7 9 F
86.6 59 B	80.7 55 B	76.4 52 B	61.3 41 D	
86.6 59 B	78.6 53 B	73.5 49 C	61.3 41 D	
84.6 58 B	78.6 53 B	69.4 47 C	61.3 41 D	

The 18.7 point is an outlier that is drastically changing the T scores. If we delete this outlier and recalculate we obtain Table 11A-8

Table 11A-8. Raw Scores, T Scores and Grades with N = 36 and Use T-Score Grades for an Average Class

90.0 64 A	84.6 59 B	78.0 52 C	69.4 44 C	61.3 36 D
89.7 64 A	84.6 59 B	76.4 51 C	69.4 44 C	59.5 34 D
89.7 64 A	81.6 56 B	76.4 51 C	66.7 41 D	59.2 34 D
89.3 64 A	81.6 56 B	76.4 51 C	65.8 41 D	58.8 34 D
86.6 61 B	80.7 55 B	76.4 51 C	65.8 41 D	18.7 — F
86.6 61 B	80.7 55 B	76.4 51 C	61.3 36 D	
86.6 61 B	78.6 53 B	73.5 48 C	61.3 36 D	
84.6 59 B	78.6 53 B	69.4 44 C	61.3 36 D	

Table 11A-9 shows the use of T scores if the class is considered to be exceptionally good. The outlier score of 18.7 is ignored.

Table 11A-9. Raw Scores, T Scores and Grades with N = 36 and a Class of Exceptional Students with the T Scale: A $\geq$ 57> B $\geq$ 47 > C $\geq$ 37 > D $\geq$ 27 >F (Chesier, 1975)

90.0 64 A	84.6 59 A	78.0 52 B	69.4 44 C	61.3 36 D
89.7 64 A	84.6 59 A	76.4 51 B	69.4 44 C	59.5 34 D
89.7 64 A	81.6 56 B	76.4 51 B	66.7 41 C	59.2 34 D
89.3 64 A	81.6 56 B	76.4 51 B	65.8 41 C	58.8 34 D
86.6 61 A	80.7 55 B	76.4 51 B	65.8 41 C	18.7 — F
86.6 61 A	80.7 55 B	76.4 51 B	61.3 36 D	
86.6 61 A	78.6 53 B	73.5 48 B	61.3 36 D	
84.6 59 A	78.6 53 B	69.4 44 C	61.3 36 D	

We could keep changing grading scales, but doing this will not answer the question "Which grading scale should we use?" If we told the students in the syllabus that a particular grading scale would be used, we have to use that scale or one that is more generous. If the syllabus was vague, then the answer is "it depends." We would not use a T scale for an engineering class. Beyond that, we would want to know much more about the students and the course. Are the students first year, sophomores, juniors or seniors? How good are the students? Is this considered a difficult or easy course? And so forth. Note that the grades for most students can shift a letter grade quite easily, and some students' grades shift two letter grades.

CHAPTER 12

STUDENT CHEATING, DISCIPLINE, AND ETHICS

Cheating is a fact of life, whether in universities or in society in general. But you can drastically reduce the incidence of cheating in your classes by taking simple precautions. This chapter should help you prevent cheating. Related issues about ethics and student discipline are also considered.

12.1. SUMMARY AND OBJECTIVES

After reading this chapter, you should be able to:

- Define methods to increase the ethical behavior of your students.
- Discuss the appropriate methods to handle cheating at your university.
- Develop methods to handle other disciplinary issues.
- Introduce ethics into your engineering course in short segments at the appropriate time.

12.2. CHEATING

Most engineering professors agree with Gregg (1989) that cheating "must not be tolerated in any form." Despite this, many graduates admit that they have cheated sometime during their college career. In one older study 56% of a graduating class of engineering students admitted to having cheated in college (Todd-Mancillas and Sisson, 1986), while in another study 82% of engineering students engaged in some type of cheating (McCabe and Trevino, 1997). More recently, Carpenter et al. (2006) found that 96.3% of a sample of 643 undergraduate engineering and pre-engineering students had performed at least one act that could be considered cheating. However, many students did not believe that all of these acts were cheating. Apparently, the use of technology (e.g., as a web-based quiz) or out-of-class exams changes the students' definitions of cheating. Harding et al. (2012) asked 388 engineering students at three schools if they had cheated on an in-class exam during the previous term. Test cheating was self-reported by 32.2% of the students. It is much better to prevent cheating than to have to deal with it after the fact.

What leads to increased cheating? In other words, if we wanted to design a course to increase cheating what elements would we build into the course? Reviewing the extensive literature on cheating that ranged from the ancient Greek Olympics to modern courses, Lang (2013) came up with five elements that increase cheating. Stated positively, the five elements that decrease cheating are:

1. A strong emphasis on learning. Instead of emphasizing doing well on tests, emphasize learning (see Section 15.6.3).
2. Reduce the stakes of assessments. For example, give many tests so that everything does not depend on the performance on one test.
3. Rely on intrinsic motivation. Extrinsic motivators often introduce competition, which can lead to cheating. Intrinsic motivators do not lead to cheating. If you can figure out how to make students "see the course material as intrinsically fascinating, useful, or beautiful" (Lang, 2013, p. 152) they will be intrinsically motivated. Since most engineering material is useful, convincing students that it is useful should not be extremely difficult. Using intrinsic motivation is the most important element.
4. Success depends on student effort. Increase the student's self-efficacy by arranging that students who learn more will have better outcomes. For example, students should have enough time on tests that they can logically determine a solution path.
5. Students' peers disapprove of cheating.

The first four elements are under the control of instructors when they design their courses. Perhaps surprisingly, if instructors increase these four elements student learning also increases. Mastery learning (Section 7. 7) automatically satisfies elements 1, 2 and 4, which helps to explain why it works. Projects (Sections 9.2.4 and 11,5), competitions (Section 9.2.8), and service learning (Section 7.10) often tap into intrinsic motivation. The fifth element depends on the environment of the institution and requires sustained effort from the administration and faculty to change.

Another element that Lang (2013) discusses, but does not list as key, is:

6. Fairly high chance of being caught. If few of the top five elements are in play, instructors can still reduce cheating with due diligence. However, unlike the first five, this element probably does not increase learning.

12.2.1. Prevention of Cheating

The best method for reducing large scale cheating is to create an atmosphere that is not conducive to cheating (Eble, 1988; Kibler et al., 1988; Lang, 2013). Probably the best way to do this is to have a well-functioning, student-run honor code. There is cheating at schools with honor codes, but less than at schools without honor codes (McCabe et al., 1999).

When good rapport exists between students and professor and among students themselves, cheating is drastically reduced. It is much easier to cheat when a professor is cold and aloof. A student who feels like a number and knows that the professor does not know her or his name finds it easier to cheat than a student who is known to the professor by name. Students cheat significantly less in a class with shared objectives, with straight scale grading that is not competitive, where students have some control over how they are assessed, and where there is an obvious excitement in learning. Any class where students feel that the professor is a partner in learning will have a low incidence of cheating.

Professors who develop a reputation for writing fair tests and grading fairly will have less cheating on their tests than professors with a reputation of writing unfair tests or of being "super hard" graders. Students must be challenged, not overwhelmed.

Reducing anxiety on tests also decreases cheating and increases learning (Kibler et al., 1988; Lang, 2013). The pressure of any one test can be reduced by giving numerous quizzes or tests but if not enough time is available for the test may increase surface learning (students just learn what they think they need for the test instead of trying to understand, which is deep learning, see Section 15.3.1). Equal access to test files reduces the urge to cheat on the part of those without access. Access to the professor and TAs for help and a help session immediately before the test make the course seem fairer and help reduce pressure. Open book exams or tests with equation handouts or key relations charts help reduce pressure and eliminate use of illegal cheat sheets.

Before a test is administered, some commonsense security measures can reduce the temptation to cheat. Make up a new test shortly before the test date. Have a secretary, not a work-study student, do any typing and make the copies. Any waste copies should not be thrown away (students have been known to search waste baskets) but should be kept with the other tests and discarded after the test. Any computer files not secured by a password should be deleted or the disk should be locked up. Test copies should be locked up, taken home, or craftily hidden. Even a normally honest student may be sorely tempted if a copy of the test is sitting out in plain view on a desk. Make up extra copies of the test, but number the copies so that you will know exactly how many have been distributed.

Since cheating usually occurs during the test, discuss cheating the class period before the first test. Since students often define cheating differently than faculty, explicitly define acts that you consider are cheating. A little bit of humor can help get the point across and make the discussion less threatening. Tests with long-answer questions with many calculations are the most difficult to cheat on. Multiple-choice problems are the easiest to cheat on, and if other precautions are not taken may invite cheating. Short-answer problems are intermediate. On multiple-choice tests the use of alternative test forms that have either the questions or the answers in different order will reduce cheating. Alternate test forms with different values in calculations also reduce cheating.

The most common way to prevent cheating is to make cheating difficult so that it is likely that cheaters will be caught. Proctoring exams is absolutely necessary. In large classes both you and the TAs should proctor the test. Proctoring has a major deterrent effect on cheating (Kibler et al., 1988). The proctoring can be done in such a way that it is clear that the proctors are alert so that they can help students with questions. Stationing a TA at the back of the room is an effective deterrent in large lecture halls since students cannot easily keep track of the proctor's location.

If at all possible, have the students sit in alternate seats since this drastically reduces cheating of the wandering eyes variety. If a large enough room is not available, consider using two rooms. Assign students to each room in advance and have each room proctored. Or use alternative test forms that have either the questions or the answers in different order, or use different values in calculations.

Before the exam starts have students place books underneath their desks unless the test is open book. Since many calculators and cellphones can store significant amounts of alphanumeric data, they have become possible cheat sheets. The temptation to use them in this way can be reduced if you stroll about the room while looking for students who need help. Many professors ban the use of cell phones during tests. Students should not be allowed to share calculators unless a TA clears the calculator first. The significance of cheat sheets is eliminated if every student is allowed to bring one in or if the test is open book.

Since the purpose is prevention rather than proof of cheating, take action as soon as something suspicious happens. Standing near the student (while waiting to answer the questions of other students) may be a sufficient deterrent. Asking the student if he or she has a question is a subtle way of letting the student know that you are watching. If the situation persists, ask the student to move to a less crowded spot. If the student prefers to stay put, suggest that you prefer that he or she move. Some professors announce to the class that students should not look around the room. This can be effective, particularly if the professor looks at the suspicious student, but it is a bit distracting for the class.

In very large classes where the professor does not know each student by name and may not even recognize some faces, it is fairly common to use picture IDs to prevent "ringers" from taking the examination for someone else. The IDs can be placed on the corner of the desk or they can be shown to the TA as the student turns in the test. Of course, the ID may be false.

The chaos of test turn-in time also invites cheating (Felder, 1985). Students see someone else's solution or the professor's solution and then quickly change their answers. This can be prevented by making everyone stop writing at a particular time. The professor's solution can be guarded until after all tests have been turned in. The professor can have the TAs collect the test while watching for suspicious activity.

As soon as the tests have been collected, log them in. In this way you know immediately who did not take the test. Tests need to be kept secure after the exam is over. Students have been known to steal a large number of tests so that the exam cannot be graded. Both the professor and the TAs need to be careful not to lose any tests. Losing a student's test creates major difficulties.

Be sure that the graders make a mark on every page of the test perhaps including the backs of pages so that students cannot claim that the grader did not see a page. It is best to use bound examination books so that pages cannot be inserted after the test has been returned. If a stapled test is used, carefully staple all the pages together when the test is returned. It is extremely difficult to add a page without making an extra staple hole in the other pages.

Any students who are suspected of being dishonest should receive extra care in grading. You can spend a little extra time going through their tests in detail to be sure that the grading is correct. Make a copy of the suspect's test before it is returned. Who is a suspect? Any student who has been caught cheating previously, who has been suspected of cheating, or who has received significant points by having a previous test regraded. It is best to handle these cases quietly without the help of the TAs since the student may well be innocent.

Procedures for homework, projects, and take-home tests are similar, but it may be harder to catch cheaters. If a take-home assignment is to be done independently, this requirement needs to be stated in writing on the top of the assignment. Despite this, collaboration on take-home assignments, even among graduate students, is very high (Todd-Mancillas and Sisson, 1986). The easiest way to decrease cheating on take-home assignments is to make them a small percentage of the course grade and then encourage students to collaborate (Felder, 1985).

Plagiarism is the most common form of cheating (Newstead, 1998). The rules for plagiarism of papers and of computer code need to be clearly spelled out (Walworth, 1989). Since different cultures define the act of sharing answers with a friend in different ways, professors need to share their definitions and rationale with the class. Many students simply do not know the rules about plagiarism, so this discussion is particularly important. To make the discussion positive, present it in a positive form by including it in a larger discussion on the importance of engineering ethics and the proper method of citing sources (see Section 12.4). Since copy-and-paste is so easy, lazy students may be blatant in their plagiarism. Relatively sophisticated but dishonest students may try to hide their plagiarism by changing the context of copied material, listing false references, and including a bibliography but no citations in the paper (Ryan, 1998). Plagiarism can be detected automatically in papers with commercial software such as Turnitin and iThenticate and in code (Joy et al., 2011). McCuen (2008) explores the thought process of students who commit plagiarism. Students are less likely to plagiarize if they know the paper will be checked. A student who believes that he or she will receive more credit by properly citing sources is less likely to plagiarize.

Graduate students have been known to plagiarize, particularly in their literature reviews. We tell PhD students before they write their theses that about the only action that will prevent them from graduating is to plagiarize. We also mention that the university has a license for plagiarism checking software. Since they have worked long and hard to get to the point they are at, they do not risk failing because they were too lazy to rewrite some passages from the literature.

12.2.2. The Cure for Cheating

Once cheating has been detected, resolving the situation can be very painful and time consuming. Cheating must be fully documented. If possible, have someone witness your proof. If there is reasonable doubt that cheating has occurred, the best course is to put the student on your suspicious list and be more vigilant the next time.

If the proof of cheating is clear, then obtain a copy of your university's regulations and read them very carefully. Courts have upheld the principle that some form of due process must be followed in academic discipline cases [see Kibler et al. (1988) for citations of the court cases]. Follow your university's regulations. Most universities have developed regulations that provide students with appropriate due process. If you make allegations of cheating in good faith and follow your university's regulations, then you will be well protected from personal liability even if the student is found not guilty (Kibler et al., 1988). However, you will be liable if the student is found not guilty and you impose penalties anyway.

Some universities allow the professor to discuss the case with the student, and *if* the student confesses, the professor can decide the penalty. This can range from a zero on the test to a lower grade in the course. Kibler et al. (1988) suggest that this informal procedure without reporting the case is somewhat dangerous. If the student later recants and claims that he or she was coerced into confessing, the professor may be liable even though the student signed a confession. It is safer to go through the formal university channels. The university committee also has access to records that may show that the student chronically cheats, which will result in a more severe penalty. Lowering the student's grade without discussing the allegations with the student is unwise since due process has clearly been denied the student, and the professor may be liable.

Stevens (1996) agrees that professors should first check their university's rules, but he recommends professors use an informal procedure. Inform the student orally of the charges and the potential penalties. There must be an appeal procedure, such as reporting the alleged offense to the Dean of Student's office for a formal hearing. Explain the appeal procedure to the student. If potential penalties are mild (e.g., a zero on the test), Stevens suggests holding a private investigative hearing. The hearing can be done immediately and does not have to be drawn out. Listen to the student, decide if the student is guilty, and if guilty select a penalty. Since the professor has acted as prosecutor, judge and jury, the reason for the appeal procedure is clear. If the student requests it, use the university's formal procedure. Students who are guilty may well accept your penalty instead of risking a formal hearing.

We repeat: It is much better to prevent cheating than try to deal with it once it has occurred.

12.3. CLASSROOM INCIVILITY AND OTHER DISCIPLINE PROBLEMS

Although cheating is the most prevalent discipline problem, professors have to deal with classroom incivility and other discipline problems. Once again, prevention is the best policy. Professors who develop rapport with students, are fair and accessible, are excited about the material they are teaching, and try to function as an ally to the student in learning the material have few cases of classroom incivility or discipline problems. However, one must know where to draw the line. Students are similar to children in that they test professors. Just as a parent must know when to stop this testing, professors must be able to tell students that their requests are unreasonable. This can be achieved with friendliness but at a certain professional distance (see Chapter 17).

Classroom incivilities including talking, reading newspapers, texting, arriving late or leaving early, surfing the web, talking, showing disrespect for others, and sleeping all disturb other students. In addition, we have a rule that students are not allowed to wear headphones in class because a student wearing headphones cannot, even by accident, pick up anything of value from the lecture. State both the rules and the reasons for the rules (protecting the learning environment for all students) during the first class period. Offenders can be asked politely to stop. If the offense continues, the student can be called in for a private discussion focused on how his or her behavior affects the learning environment in the class.

Peer pressure can be a strong deterrent for anti-social behavior. Listing the results of a student survey of uncivil behaviors (Bjorklund and Rehling, 2010) in your syllabus may decrease their frequency. The top dozen uncivil behaviors, with scores above 3 on a 5-point Likert scale were:

1. Talking after being asked to stop
2. Under influence of alcohol or drugs
3. Ringing cell phone
4. Talking loudly with others
5. Nonverbal disrespect for others

6. Swearing
7. Sleeping
8. Disparaging remarks
9. Arriving late or leaving early
10. Text messaging
11. Packing up books early
12. Doing non-class activities on computer or smart phone.

If there are significant problems during the term, another approach is to do a survey of the class and ask which behaviors they find the most disturbing or uncivil. Then if you ask students to stop talking, you are enforcing the class' rule, not yours.

Late arrivals are mildly disruptive. And a latecomer who then asks questions about material that has already been covered can be quite disruptive. Some professors lock the door when the bell sounds. This approach seems extreme. Talk to a chronically late student but do so in a nonthreatening manner (see Chapter 10). Perhaps there is a good reason for the tardiness, and some sort of special arrangement may be appropriate, such as transferring the student to another section. At the least you can request that the latecomer save questions about material that has already been covered until after class.

Hostile students are another problem. Hostility is most prevalent following a test, but some students start the semester hostile. Hostility following a test can usually be deflected by having a fair regrading procedure and by asking the student to talk to you after class. Since this type of hostility usually decays rapidly, a good strategy is to give the student time to cool off and then listen to her or him. A chronically hostile student is a different matter. Look at the student's file and talk to the undergraduate program advisor and to professors who have had him or her previously. This information may give a hint of how to proceed. If there is no hint, you can call the student in for a chat. Try to be non-defensive, express concern as to the reasons for the behavior, stress the need for professionalism and the consequences for hostile behavior at work, and listen to her or him. Don't expect miracles but see if an accommodation can be worked out.

Students with excessive absences cause problems since they skew the curve downward on tests, are usually late or don't turn in homework, and often complain about the course. In some courses, such as laboratories and seminars, it is appropriate to require attendance and reduce the student's grade accordingly for absences. Many students, and some professors, think that attendance in lecture courses should be optional and what the student learns should determine his or her grade. Keep track of attendance and point out the excellent correlation between attendance and learning. Refusing to grade on a curve prevents excessively absent students from skewing the grading. If you want to grade on a curve, one solution is to plot the scores of students who have attended at least some minimum number of classes and use this curve to set the course grades. Then on the basis of this curve, students with excessive absences receive whatever grade they have earned. If you do this, be sure to explain the grading procedure clearly in advance.

Students do procrastinate and often turn assignments in late. Accepting late assignments at full credit does not seem fair to students who have done the work on time, and it rewards students turning assignments in late for bad behavior. On the other hand, following a policy of never accepting late assignments seems overly rigid. We tell students that we follow the same policy as companies: *late work is accepted grudgingly*. Thus, there is a penalty for turning in assignments late. Students sometimes miss tests, with excuses ranging from oversleeping (probably true), to being sick (maybe true), to the death of a grandparent (possible). The easiest policy for dealing with absences is to automatically discard the lowest test score that the student receives during the semester. A test missed for any reason becomes a zero and is discarded. A student who protests can be offered an opportunity to take the test for practice. A second policy that some professors use is to allow makeups only for illness with a signed form from a medical doctor or an obituary for death of a family member. A third possible policy is to write a makeup test for each test. A procedure we have used is to allow students who have proof of being ill to take a makeup. For everyone else (e.g., plant trips or oversleeping) we write a single, cumulative makeup taken at the end of the semester. When given the choice of taking a cumulative exam or rearranging a plant trip, students often find the company is willing to accommodate their schedule.

Students argue about grades after each test and at the end of the semester. A formal regrade policy (see Section 11.3.3) is useful. For arguments at the end of the semester, students should be shown the courtesy of being listened to. Occasionally we have found that a mistake was made and the grade needs to be changed. At some universities a discussion with the professor is the first step in a formal grade appeal procedure. Changing student grades unless a mistake has been made in recording the grade or in adding points will drastically increase the number of regrade requests the professor gets in the future.

On rare occasions one hears stories of students trying to buy grades with money, gifts, or sexual favors: “Professor, I’d do *anything* for a B in this class.” Since the offers are usually not explicit, the best response is to act as if nothing unethical was intended: “Here’s a study schedule with ten hours a week on this course including an hour a week of tutoring with the TA. If you follow this you will be sure to improve your current grade.”

12.4. TEACHING ETHICS

Teaching students to become ethical engineers is important. This subject is particularly appropriate for this chapter because it is improbable that students who cheat their way through school will suddenly become ethical engineers upon graduation. To some extent cheating does predict unethical behavior in the workplace (Carpenter et al., 2004). Although practicing engineers rarely turn to the codes of ethics, the codes of ethics developed by different engineering societies help to focus a discussion on ethics (Colby and Sullivan, 2008). After trying different codes, in classes with students from different engineering disciplines we have settled on the very short code developed by the Engineers’ Council for Professional Development (ECPD) which became ABET (see Section 4.7) shown in Table 12-1. This code has been incorporated into most of the longer codes of the different engineering societies. In classes where the students are all in the same engineering discipline we use the code from the engineering society for that discipline (e.g., AIChE, ASCE, IEEE). Sheppard et al. (2009, p. 141) note that all of the codes are similar in articulating “the overriding importance of competence, responsibility, accountability, and fairness.” They note later (p. 143) that “quality *is*, in essence, an ethical dimension of engineering.”

If desired, after the introduction of one of the codes of ethics, it is relatively easy to segue into cheating, which clearly does not result in quality or fairness. An advantage of this approach is that it clearly couples cheating with unethical behavior. Since cheating is not the main focus of the discussion, the students are less likely to feel accused and become defensive.

Table 12-1. ECPD Code of Ethics (© 1977 American Association of Engineering Societies. Used with Permission)

Fundamental Principles
Engineers uphold and advance the integrity, honor, and dignity of the engineering profession by:
I. using their knowledge and skill for the enhancement of human welfare;
II. being honest and impartial and serving with fidelity the public, their employers, and clients;
III. striving to increase the competence and prestige of the engineering profession; and
IV. supporting the professional and technical societies of their disciplines.
Fundamental Canons
1. Engineers shall hold paramount the safety, health, and welfare of the public in the performance of their professional duties.
2. Engineers shall perform services only in areas of their competence.
3. Engineers shall issue public statements only in an objective and truthful manner.
4. Engineers shall act in professional matters for each employer or client as faithful agents or trustees, and shall avoid conflicts of interest.
5. Engineers shall build their professional reputation on the merit of their services and shall not compete unfairly with others.
6. Engineers shall act in such a manner as to uphold and enhance the honor, integrity, and dignity of the profession.
7. Engineers shall continue their professional development throughout their careers, and shall provide opportunities for the professional development of those engineers under their supervision.

Professors cannot assume that students are automatically ethical. Ethics must be instilled in students (Walworth, 1989)—most effectively by including the subject throughout the curriculum instead of adding an ethics course or lecture at the very end of the student's career. Ethics can be introduced in a "just-in-time" format in every engineering class. When the ethical issue comes up, discuss the ethics involved. It is helpful to model and then require students to either use an ethical decision-making process similar to the one shown in Table 12-2 or adapt an engineering design process to ethical problems (Whitbeck, 1995). The latter approach has the advantage of emphasizing that ethical situations are often open-ended with a wide range of possible solutions.

A variety of methods can be used to instill ethical behavior. A few of these methods are:

1. Model ethical behavior at all times. The ethics of being an engineering professor are discussed in Chapter 17.

2. Before the first test in every course discuss the need for ethical behavior in engineers. Note that you expect students to practice ethical behavior. Then discuss the rules for honesty in taking a test.

3. Engineering professional ethics can be taught in stand-alone 1 to 3 credit courses, as part of required technical courses (Harris et al., 1996), or in required professional seminars.

Table 12-2. Ethical Decision-Making Process (Courtesy of Susan Montgomery and Nicholas H. Steneck)

1.	Define the problem. What are the technical goals? Facts? Ethical dilemmas?
2.	Define stakeholders. Who is affected? Major/average/minor? What is their interest?
3.	Research the problem. Engineering standards, including safety and environment, ethical standards
4.	Explore possible solutions. Effect on stakeholders, compare against ethical standards.
5.	Finalize your decision. Review impacts on all stakeholders.

Of course, it would be preferable to include ethics throughout the curriculum. Our experience is in professional seminars. We believe that professional seminars should have multiple sessions on ethics. The appropriate code of ethics should be distributed to all students and then discussed. The ECPD code (Table 12-1), is short and is part of the codes of many engineering societies. The first fundamental canon, "Engineers shall hold paramount the safety, health, and welfare of the public in the performance of their professional duties," is included in most other engineering codes. We discuss what this means with specific examples. Unfortunately, it is easy for students to read any code without thinking about its ramifications. As a take-home quiz we pass out ten of the short ethical scenarios from Mathews et al. (2006) that asks students to first choose an ethical option from the choices presented. The scenarios are somewhat vague since they do not have much information, and most of the scenarios have multiple correct answers. Both of these characteristics are common for real ethical dilemmas (Jonassen and Cho, 2011). The second, and more difficult, part of the quiz requires the students to identify a portion of the code that justifies their answer. The first two questions are done in small groups in class followed by class discussion. The entire quiz is discussed in the next class after it has been handed in. For some of the juniors this is the first time they have seen ill-defined problems with multiple correct answers in an engineering course.

4. In discussions of ethics the professor can usefully play the role of devil's advocate. Florman (1987) presents an interesting hypothesis that laws have taken the place of self-policed ethical codes and thus most of the codes are obsolete. He recommends a common-sense approach to ethics. His first postulate is:

> Don't break the law.

Since most engineering failures are due to human error or sloppiness, his second postulate is:

> Be conscientious, that is, careful, hardworking, dedicated, and innovative.

Florman notes that whistle blowing is usually unnecessary. He suggests trying to influence events without becoming excessively disruptive, of working within the system.

5. Case studies (see Section 9.2.4) with class discussion or a class debate are excellent for involving students in a discussion of ethics (Colby and Sullivan, 2008). Case studies are appropriate as part of a regular class, as part of a seminar class, or in a class devoted to ethics. For example, in a senior design class the ethics of environmental problems can lead to a lively

hour of discussion. Or the students can discuss or debate whether an engineer working on offensive weapons in the defense industry is satisfying fundamental canon 1. The explosion of the space shuttle *Challenger* serves as an interesting case study for any engineer (Florman, 1987), but to current students the *Challenger* disaster is ancient history. The National Academy of Engineering Online Ethics Center http://onlineethics.org/ has a number of more up-to-date cases and scenarios plus historical cases. Methods to analyze cases are discussed in standard engineering ethics textbooks (e.g., Fleddermann, 2011; Harris et al., 2014).

6. Three videos produced by the National Institute for Engineering Ethics can be useful, but in our experience students find the two oldest videos, *Gilbane Gold* (1989) and *Incident at Moralles* (2003), to be dated. The third video, *Henry's Daughters* (2010), is more recent. The videos can be obtained from the Murdough Center for Engineering Professionalism at Texas Tech University http://www.depts.ttu.edu/murdoughcenter/.

7. Bringing back recent alumni who have faced ethics situations is more realistic to students because they can more easily imagine confronting these problems themselves.

8. In the senior design course we discuss the ethics of job hunting, interviews, and plant trips. We emphasize that cheating on an expense account will get the engineer fired, and that reneging on a job offer is not the appropriate way to start an engineering career.

9. Passino (1998) has interesting ideas for large classes on ethics. For example, he uses an "attendance question" (that is, a one-minute quiz) at the end of each class to obtain the attendance list and comments that start the next week's class. Passino knows that some students will start sneaking in late once they realize that the attendance questions are always at the end of class. He ties this behavior to professional behavior on the job.

10. The typical ethics discussions consider only individual ethics, which are important but do not change systemic problems in engineering education. After individual ethics, try being bold and covering engineering for social justice (Baillie et al., 2012; Lucena, 2013; Nieusma and Riley, 2010; Riley, 2008). One approach that is palatable to most students is to start with a case study of development work by a non-governmental organization (NGO) such as Engineers without Borders (EWB) [the Online Ethics Center at the National Academy of Engineering has a case study on EWB]. The next step would be to transition to service learning (see Section 7.10) and have students actually work with EWB or another NGO.

Ethics is a dry subject only if presented as a dry subject. A little creativity can make the ethics portion of a class lively and interesting. The best essays we have read on the critical importance of embedding ethics and professionalism into engineering education are chapters 16 and 17 of Sheppard et al. (2009). We recommend all engineering professors read these 19 pages.

12.5. CHAPTER COMMENTS

In a class on teaching, the material in this chapter can be fun to teach. Every student and professor knows stories about the zany things students have done to cheat or to escape doing work. A little humor can make this interesting and counter the seriousness of the topic. As for cheating, we cannot emphasize too much that prevention is better than a cure. One additional method, which is outside the scope of this chapter, is to develop a student-run honor code. Schools with well-functioning honor codes have a significantly lower incidence of cheating.

HOMEWORK

1. Obtain a copy of the regulations for handling cheating at your university. Compare the policies of your university to the more general discussion in this chapter.
2. From newspapers or professional publications find a current news item that involves ethical issues. Develop a five-minute presentation to include this issue in an engineering class. Develop a plan for student discussion based on Table 12-1 or other engineering code of ethics.
3. List additional cheating methods and how to handle them.
4. Select a short case or scenario from http://onlineethics.org/ and apply the ethical decision-making process to it.

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CHAPTER 13

PSYCHOLOGICAL TYPE AND LEARNING

How do individuals learn? What can teachers do to aid learning? Why do different teaching methods have different effects on individuals (or "why doesn't everyone learn the same way I do?"). Complete answers to these and related questions are not known despite years of intensive research; however, what is known can be helpful to professors in understanding the learning and teaching processes. Chapters 13 through 15 explore these questions and suggest ways of incorporating them in engineering education. Chapter 14 examines two theories of cognitive development, Piaget's and Perry's, and offers implications for engineering education. Piaget's theory leads to the learning theory known as constructivism, which is dealt with in Chapter 15, along with learning styles, Kolb's learning cycle, how people learn, and, finally, motivation.

This chapter focuses on the natural differences among students that need to be considered in the planning of instruction and for handling interpersonal relationships. By accounting for such differences we can retain the students we have and also attract the nontraditional groups that are underrepresented in engineering. As Sections 13.3 through 13.5 show, the personality instrument discussed in this chapter, the Myers-Briggs Type Indicator (MBTI), has proven to be a successful tool in engineering education for recognizing and accommodating these differences.

The essence of the theory behind the MBTI is that "much seemingly random variation in behavior is actually quite orderly and consistent, being due to basic differences in the way individuals prefer to use their perception and judgment" (Myers and McCaulley, 1985, p. 1). "Perception" refers to the ways that we process information or become aware of the world around us. "Judgment" has to do with the ways we make decisions on the basis of what has been perceived. These ideas are based on the theories of the Swiss psychologist Carl Jung (1971) and their application and extension by Katherine Briggs and Isabel Briggs Myers. The MBTI has been used in education and industry as well as career and marriage counseling to help identify personality types in order to improve communication and open the possibilities for learning. Such knowledge is very important for professors and beneficial for students.

An indicator, not a test, the MBTI is a self-reporting instrument that offers a forced-choice format between equally valuable alternatives. In answering the questions or responding to certain word-pairs, we can discover our preferred way of dealing with, and living in, the world. Intrinsic preferences, though possibly inborn, aren't always available to our conscious minds. The way we are raised and the situations we confront may force us to react in ways opposed to our inherent preferences. The MBTI allows us to arrive at a "reported" type and then examine the conclusion in light of our experiences, beliefs and feelings, all the time being free to accept or reject the result. The CCP (formerly known as Consulting Psychologists Press) claims "The *Myers-Briggs Type Indicator*® (MBTI®) assessment is the best-known and most trusted personality assessment tool available today. As many as 1.5 million assessments are administered annually to individuals, including to employees of many Fortune 500 companies" CCP (2009). A collaborating statement from a more unbiased source but with reservations was reported by Lok (2012): "'The Myers-Briggs assessment is probably the personality test most widely used by scientists and the general public,' says John Lounsbury, a psychologist at the University of Tennessee in Knoxville who has conducted personality tests on Oak Ridge scientists. He and other academic psychologists say that Myers-Briggs is overly simplistic and misses out a few key traits, and that better tests exist. However, it remains popular because it is easy to understand, many people have been trained to administer it and there is a large body of interpretive books, websites and other materials that further boost awareness of the test." Despite the concerns of psychologists, many people have found the MBTI to be useful for understanding and improving human interactions.

The MBTI does not merely classify people. Type does not refer to something that is fixed, permanent. Each type has its own ways of reacting to situations, but no one is true to type all the time. As McCaulley et al. (1983) point out, good type development often involves responding in ways that one does not spontaneously prefer. "The word *type* as used here refers to a dynamic system with interacting parts and forces. The characteristics and attitudes that result from the interactions of these forces do differ, but the basic components are the same in every human being" (p. 397).

13.1. SUMMARY AND OBJECTIVES

After reading this chapter you should be able meet the following objectives:

- Describe briefly the background of the Myers-Briggs Type Indicator and its development from the ideas of Carl Jung.
- Discuss the attitudes and functions of conscious thought and how the four preferences interrelate to form the matrix of sixteen personality types.
- Consider your own preferences in terms of the descriptions for each attitude and function, arriving at a rough estimate of your own type.
- Explain the importance of considering type differences among engineering students in the development of instructional materials, tests, and evaluations.

13.2. FROM JUNG TO THE MBTI

The seminal work on type theory was done by Carl Gustav Jung, the Swiss psychologist and contemporary of Sigmund Freud. His study P*sychological Types* was published in 1921 after almost twenty years' work in treating individuals and discussing problems and solutions with colleagues, as well as "from a critique of [his] own psychological peculiarity" (Jung, 1971, p. xi). Jung looks at the problem of type in the history of classical and medieval thought as well as in biography, poetry, philosophy, and psychopathology.

Katherine Cook Briggs was a lifelong student of the differences among individuals and how they relate to the way in which one functions in the world. In part her interest in personal differences grew out of her desire to be a writer and create fictional characters, and for this reason she was particularly interested in Jung's treatment of biography in his book. Discovering Jung's work in the English translation in 1923, Briggs is alleged to have said, "This is it" (Saunders, 1991, p. 59). Unfortunately, she was so impressed with Jung's work and terminology that she burned her own notes and adopted the latter's terminology. She shared this interest in personality with her daughter Isabel (later Isabel Briggs Myers) who continued studying type. *Gifts Differing, by* Myers and Myers (1980) gives an excellent discussion of their theory. With the onset of World War II, Myers desired "to do something that might help people understand each other and avoid destructive conflicts" (Lawrence and Sommer, 2009). She decided to find a way to put the theory to practical use and from this came the idea for a "type indicator." She first developed an item pool that would reflect the feelings and attitudes of the differing personality types. Next, items were validated with friends and family followed by collecting data on 5000 high school students and 5000 medical students. After Consulting Psychologists Press https://www.cpp.com/products/mbti/index.aspx took over publication from Educational Testing Service in 1975, use of the instrument expanded greatly. It is also being used in England and Australia, and has been translated into more than 20 languages. According to McCaulley (1976), the fact "that similar career choices by the same types occur in disparate cultures suggests that Jung's theory taps some fundamentally important human functions that cut across cultural teaching." The third edition of the MBTI Manual was published in 1998 (Myers et al., 1998).

Nardi (2011) looks at hardwiring directly in his brain studies by using a 20-sensor EEG on 60 college students. He catalogs brain areas in relation to certain personality characteristics, noting how types correlate to usage levels of brain states, of how similar types use the same brain regions. For now, the extent of the study's qualitative (as opposed to quantitative) results, though, keep it from being truly definitive.

13.3. PSYCHOLOGICAL TYPE

13.3.1. Attitudes and Functions

In *Psychological Types*, Jung postulated that everyone has a basic orientation to the world that indicates the directions in which energies or interests flow: to the outer world of people and events (extroversion, E) or to the inner world of ideas (introversion, I). He referred to this as an *attitude* toward the world. Either type, in the conscious aspects of life, processes information either through the senses (S) or by intuition (N) and makes decisions on the basis of this information either by logical, impersonal analysis (thinking, T), or on the basis of personal, subjective values (feeling, F). Jung regarded both thinking and feeling to be rational processes and so the term "feeling" here does not mean irrational. As to why there

Table 13-1. The Four MBTI Preferences

Direction of energy or interests	
(Outer world of people)	Extroversion
(Inner world of ideas and actions)	Introversion
Preference of perception	
(Immediate and practical experience)	Sensing
(Possibilities and meanings of aspects of experiences)	Intuition
Preferences for decision making	
(Logical, objective)	Thinking
(Subjective, personal, value-based)	Feeling
Orientation to outside world	
(Ordered, planned)	Judgment
(Spontaneous, adaptive)	Perception

are four functions (S, N, T, F), not more or less, Jung (1971, pp. 540–541) says he arrived at that number on purely empirical grounds. Through sensation we establish what is present, with its meaning determined through thinking. Feeling tells us its value, with possibilities delineated by intuition.

To these three Jungian pairs, Katherine Briggs added a fourth: a judging (J) or perceptive (P) orientation to the world. In her research she discovered that individuals tend to function primarily in either the perceiving or the judging mode. That is, some people (P) like to gather more and more information and adapt to situations as they arise; others (J) prefer more structure, and order, making lists, and trying to control events. The four dichotomies are shown in Table 13-1.

A person's preferences are indicated by these dichotomies, but each person is free to use sensing or intuition, and, similarly, thinking or feeling. As with handwriting, anyone can write using either the left or the right hand; however, most have a preference for one over the other and tend to develop the skill in one more than in the other. The four dichotomies (EI, SN, TF, JP) can be arranged in a four by four table or matrix, giving sixteen personality types from interactions. Figure 13-1 in Section 13.4 gives an example of the matrix, with breakdowns of percentages for engineering disciplines. Then brief general characteristics of each type will be given (Myers and McCaulley, 1998; Quenk, 2009; Singer, 1972). McCaulley, Macdaid, and Kainz (1985) discuss ways of estimating type frequencies among the general population.

Orientation to Life: Extroversion (E) and Introversion (I). The first pair, extroversion and introversion, focuses on how one approaches the world. Ever since Jung first posited these descriptors of behavior, the terms have become part of the language and as used here they carry the standard psychological connotations. The outer-directed extrovert enjoys social contact, depends on interaction with others for personal satisfaction, and is energized by these interactions. The inward-looking introvert, on the other hand, tends to withdraw from such interactions, prefers quiet for concentration, and is energized by being alone. The easy communication of the extrovert is a problem for the introvert, who, preferring ideas, may have trouble communicating orally. In problem-solving, the extrovert tends to place greater weight on the situation and other people's views, whereas the introvert tends to focus more on the conceptual framework of the problem (McCaulley, 1987). No one is purely extroverted or introverted, though some individuals clearly represent extremes of each type. Instead, the terms refer to preferred orientations. Anyone can exhibit both introverted and extroverted behavior. For example, an introverted teacher may approach a class with some fretfulness, mustering up all of his or her energy to begin the class, but once settled into the course, may feel comfortable and act the complete extrovert—within the confines of the class. Yet, the preferred orientation is that of an introvert. Each person carries the capability of developing both orientations but by preference tends to develop one of them. The same is true of the other three function pairs. This is an important point to remember while reading about the MBTI. Myers and McCaulley (1985, p. 5) caution that the Indicator is no substitute for good judgment and that the proper way to use it is as a stimulus to the user's insight.

Extrovert (E). Roughly 50% of the general population (CAPT, 2014); about 33% of the engineering student population (McCaulley, 1990).

- Likes people.
- Likes action.
- Acts quickly.
- Communicates easily.
- Is applications-oriented.
- Feels energized by interaction with others.

Introvert (I). 47–55% of the general population; about 67% of the engineering student population.

- Prefers quiet for concentration.
- Likes ideas and concepts.
- Has trouble communicating.
- Relies on inner illumination.
- Prefers to work alone and is energized by doing so.

Perception or Becoming Aware: Sensing (S) and Intuition (N). Sensing (S) and intuition (N) characterize the perceptive function, or how one becomes aware of, or perceives, the world. The sensing person leans toward working with known facts rather than looking for possibilities and relationships as the intuitive person often prefers to do. He or she also tends toward step-by-step analysis and prefers to work by established methods. Intuitives favor inspiration and may work in bursts, quickly jumping to conclusions or solutions. Unlike sensing individuals, they are impatient with routine and may appear to be more imprecise. Using their imaginations, they see possibilities, whereas sensing individuals use their senses and work through the powers of observation. To a sensing type, soundness, common sense, and accuracy characterize real intelligence, which for an intuitive is shown by flashes of imagination and insight in grasping complexities. Attitudes characteristically developed from the preference for intuition include a reliance on sudden insight, an interest in the new, and a preference for learning through an intuitive grasp of meanings (McCaulley, 1978). This dichotomy was included in the Index of Learning Styles (see Section 15.2.3). A synopsis of the two types shows the following [general population results are from CAPT (2014) and engineering results from McCaulley et al. (1983) and McCaulley (1990)]:

Sensing (S). 66–74% of the general population; 53% of engineering student population.

- Uses senses and powers of observation.
- Works through step-by-step analysis.
- Likes precision.
- Prefers established methods.
- Is patient with routine.
- Works steadily.

Intuition (N). 26–34% of the general population; 47% of the engineering student population.

- Is imaginative, sees possibilities.
- Relies on inspiration.
- May be imprecise.
- Jumps to solutions (is quick).
- Works in bursts.
- Dislikes routine.

Decision Making: Thinking (T) and Feeling (F). Once all the data are in, whether by sensing or by intuition, one must then decide how to process the information and come to a decision. A person who prefers to be logical and analytical, weighing facts impersonally and objectively, shows a preference for thinking (T) as the mode of decision making; someone who bases decisions on subjective, personal values and standards uses feeling (F). Both poles are accessible to everyone, and often most individuals move freely between them; however, each person has a preferred mode.

Thinking (T). 40–50% in general population; 74% of engineering students: 77% male, 61% female.

- Is objectively analytical.
- Works through cause and effect.
- Tends to be logical.
- Tends to be tough-minded.
- Tends to be impartial.

Feeling (F). 33–45% male, 65–76% female in general population; 26% of engineering students: 23% male and 39% female. Clearly, male and female engineering students differ on this dimension.

- Understands people.
- Desires harmony.
- Stresses interpersonal skills.

Living in the World: Judgment (J) and Perception (P). The fourth preference pair identifies the way an individual functions in the world. This attitude is based on the person's preference for the functions of perceiving and judging. An individual who prefers to use a perceiving function (S or N) to run his or her life tends toward being open to new perceptions, adapting to situations, and in general taking in information. This flexibility often leads to minimal planning and organization. For someone who uses a judging function (T or F) to conduct his or her outer life, the impetus is toward planning, organization, and closure. Thus, the JP preference indicates how an individual prefers to live in the outer world. If you are curious as to which of these applies to you, just think about the way you plan a vacation. Are you content to fly somewhere and then to take it from there, making plans as you go (P)? Or are you appalled by the thought of such a trip, preferring to schedule hotels, routes, stopovers, and so forth, well beforehand (J)? Do you find yourself taking in more and more information before finally writing that report—often at the eleventh hour (P)? Or do you plan it and work on it section by section, day by day (J)? As with all the pairs, both ways of living in the world are of course accessible to the individual. The dynamic interplay of all of the preferences (EI, SN, TF, JP) leads to sixteen combinations or types (see Figure 13-1).

Judging (J). 54–60% of the general population; 61% of engineering students.

- Prefers to live in a planned, orderly way.
- Likes to regulate and control events.

Perceptive (P). 40–46% of the general population; 39% of engineering students.

- Prefers to be flexible, spontaneous.
- Likes to understand and adapt to events.

13.3.2. Dominant and Auxiliary Processes

According to type theory, children are born with a predisposed preference for some functions over others (Myers and McCaulley, 1998). Lynch (1987) maintains that the dominant function is usually reflected by kindergarten age. In engineering terms, they are hardwired for a given type. This preference leads to fuller development of the preferred function and greater competence in it. A preference for sensing, for example, leads to the development of characteristics commonly seen in a practical-minded sensing individual. At the same time, the opposite pole of the preference tends to be ignored; in the above example a sensing child gives less priority to intuition and thus develops along quite different lines from another child who prefers intuition. It is apparent then that environment also plays a key role in one's development, either reinforcing or demotivating development along certain lines. This "falsification" of type can lead one to develop a less preferred function but overall still not feel in control or confident in his or her abilities. In good type development each person uses all four processes, but one process becomes the leading or dominant.

In the literature about type, the roles of the dominant and the auxiliary are often compared to those of a general and an aide. In an extrovert, the general (dominant function) is at the forefront making decisions and taking the lead, for all the world to see. As a result, we say that for an extrovert, "What you see is what you get." For an introvert, however, the aide (auxiliary function) stands as an intermediary with the outside world while the general makes plans inside a tent. The introvert, who focuses on the inner world, is difficult to know until one gets close enough to the individual. The dominant function remains hidden, which may be why introverts are often misunderstood.

To see how the dominant and auxiliary functions are determined, consider an INFP and an ENFP. For the ENFP, the fourth pair (that is, the choice between judgment and perception which indicates how the person lives in the world), here the P, indicates that this person prefers to conduct his or her outer life in the perceptive mode. So we only have to look back to the perceiving slot (the second letter, here N, intuition) to find the function used by this person in the outer world. If asked to characterize this individual's type, another person would see the intuitive aspects. Now, by definition, extroverts show the world their strongest function; therefore, the N in this case is the dominant function. For the ENFP the dominant is extroverted intuition; the auxiliary is a balancing introverted feeling (F) (introverted because the theory postulates that the auxiliary always balances the dominant, which here is extroverted), with thinking as the third and sensing as the fourth or least developed. So for an ENFP:

Dominant:	N	(extroverted intuition—what world sees)
Auxiliary:	F	(introverted feeling)
Third:	T	(extraverted thinking)
Fourth:	S	(introverted sensing—least developed function)

For an INFP the P indicates the person extroverts his or her perceptive function. Thus a judging function is dominant since an introvert's strength is within. The other perceptive function is third, and the fourth, or least developed, function, is judging (T). Thus,

Dominant:	F	(introverted feeling)
Auxiliary:	N	(extroverted intuition—what world sees)
Third:	S	(introverted sensing)
Fourth:	T	(extroverted thinking—least developed function)

These individuals trust introverted feeling the most and use it the most in directing their lives, with intuition in support of the thinking. To the world, they appear intuitive. Like most introverts they are easily misunderstood because their strength is inside, not as open to the world as the strength of an extrovert.

Note that this theory only works for people with fairly clearly developed preferences. If the score for one of the dichotomies is near neutral, the analysis can change significantly depending on which letter is used. For example, if an extrovert has the N-S score near neutral the dominant function can switch from N to S while the fourth function switches from S to N by changing the answers to one or two questions.

13.3.3. Good Type Development

Type development is seen as a lifelong process of increasing mastery or command over the functions of perception and judgment that one prefers, and corresponding but lesser development of the less interesting but essential processes. Myers and McCaulley summarize the process (1998):

- Development of excellence in the favorite, dominant process.
- Adequate but not equal development of the auxiliary for balance.
- Eventual admission of the least developed processes to conscious, purposeful use of these processes, even though this use may require the dominant and auxiliary to temporarily relinquish control in consciousness so that the third or fourth function can become more conscious.
- Use of each of the functions for the tasks for which they are best fitted.

13.4. APPLICATIONS OF THE MBTI IN ENGINEERING EDUCATION

The differences described by type theory are familiar parts of everyday life, and so the theory can be used for a wide range of applications: education, counseling, career guidance, situations involving teamwork issues, and communication. Any university counseling or psychological center can provide the necessary testing services, or individuals can be certified through the training sessions such as those offered by the Association for Psychological Type (APT), the Center for Applications of Psychological Type (CAPT), or the Consulting Psychologists Press (see Section 13.7 for addresses). Thomas (1989) offers some preliminary results on "rapid MBTI self-classification."

DiTiberio and Jensen (2008) extensively examine the relevance of the MBTI in teaching writing. Provost and Anchors (1987) discuss the uses of the MBTI in higher education. McCaulley et al. (1983) consider the results of the ASEE-MBTI Engineering Consortium of eight universities (see Figure 13-2). Their results are summarized later in this section. In the MBTI Manual Myers and McCaulley (1998) give numerous rankings of students and colleges by means of various preferences. Several authors discuss the MBTI and problem solving, with McCaulley (1987) offering a Jungian model. Yokomoto et al. (1987) discuss improvement of problem-solving performance and also consider student attitudes toward ethical dilemmas. Three ethical dilemmas were presented to students, who were required to make a decision on what further action, if any, might be taken to resolve them. Analysis of the results showed several biases arising from personality differences, with feeling types recommending action more strongly than thinking types in one situation. Campbell and Kain (1990) found that the most time-efficient types (N and J) were the least accurate. S and P types tended to be more accurate but took longer to achieve their accuracy.

13.4.1. Teaching Methods

Lawrence and Sommer (2009) synthesize learning style research involving the MBTI. The MBTI can be used to develop teaching methods to meet the needs of different types, especially on the sensing-intuition dichotomy, which has the largest effect on education. As McCaulley (1987) points out, S and N types approach problems from opposite directions: S moves from the specific to the general; N from the "grand design to the details." She then makes a telling point: "In fields with relatively equal numbers of S and N students, such as engineering, the faculty have more of a challenge maintaining student interest than in fields, such as counseling, where students and faculty are more similar" (p. 47). Smith et al. (1973) found that personality traits influence student attitude and performance in self-paced instruction. They further note that a major weakness in college teaching appears to arise from the teacher's and student's lack of recognition of each other's differences, which gives rise to the need for different learning activities. Self-paced instruction (Section 7.7), according to the authors, can be made more effective if instructional modules or packages are designed which fit different styles of student perception and judgment. Provost et al. (1987) studied a sample of professor of the year finalists to see how outstanding teachers use their type preferences. This limited study shows that type affects teaching style, assumptions one might make about teaching, and attitudes about what aspects of teaching are seen as rewarding. Outstanding teachers are able to relate to other types and to appreciate the inherent diversity.

The sensing-intuition (SN) dichotomy is perhaps the most important one for an engineering educator, both from the standpoint of the instructor and from that of the students (especially as sensing relates to mastering a body of knowledge and the corresponding skills central to a field of practice). Intuition has to do with the ability to think complexly and contextually. The percentages of type in the general and university populations alone tell a significant tale. Sensing types predominate in the general population; intuitives, in a university environment. More college professors are intuitive types than sensing types, and they tend to write exams that more frequently fit their own type (Lynch, 1987). If memorization and recall are important, sensing and judging types will perform better; if hypothesizing and essay tests are required, intuitive students will have an advantage. Aptitude tests are also designed to measure knowledge in the domain of introverted intuitives (IN). The data show that introverts consistently score higher than extroverts on the SAT-Verbal. Intuitives also consistently score higher than sensing types. The sensing-intuition differences, according to Myers and McCaulley (1998), are greater than the extroversion-introversion differences. O'Brien et al. (1998) concluded that "One of the most interesting findings was that students exhibiting the Intuitive type had significantly higher grades in the course than students preferring the Sensing type." The sensing-intuitive dichotomy is discussed further in Section 15.3.

In the classroom, the thinking-feeling (TF) preference appears to have less importance than the others, but it can be argued that a predominance of thinking types in a class could "freeze out" the few feeling types. Is it possible that feeling types self-select out of engineering because of the more impersonal emphasis of the predominant thinking types in engineering? One colleague has suggested that it might be easier to teach ethics if students were more interested in human motivations (feeling types), rather than being concerned with building the best device (ST) or developing the most elegant theory (NT). Finally, it is important to remember that type theory does not make judgments on intelligence: All types can succeed in any area, and all types are represented in every area. What is important is to work to make survival of every type easier for engineering students. Paying attention to type differences and taking them into account in teaching goes a long way toward promoting such success. The fact that certain types predominate in certain careers says more about a type's attraction to the field than whether he or she will succeed in it. Once an individual has gotten past the educational barriers to a given field, being different from the prevailing type can be an advantage since he or she will see things that others miss. Felder et al. (2002) conclude that "the MBTI is a useful tool for helping engineering instructors and advisors to understand their students and to design instruction that can benefit students of all types."

13.4.2. Motivation

The MBTI can also be used to help students if the instructor understands the ways that different types are motivated. An instructor can help students gain control over their own learning and thereby reach more students. Even something as simple as a phrasing can be important. For example, feeling types respond better to a question that is phrased "How do you feel about . . . ?" whereas the thinking type prefers "What do you think . . . ?" Also, the quickness of the N types may discourage an S type, and in a classroom the quicker student is often more praised and honored; the "slower" student quickly forms an impression that he or she is lacking what the "best" students have. We use quotation marks to indicate that intelligence is not the consideration here. In the long run, the "slower" but more thorough and accurate S may be more correct and/or successful. And if not demotivated by the instructor, such a student may be a valuable addition to the class.

13.4.3. Interpersonal Relationships

The MBTI can also be used to help teachers and administrators work together more constructively. Type data from one sample show that administrators tend to be heavily J types [86% in Lawrence's (1984) sample]. As in other areas, such as personnel cases in industry, awareness of type differences can lead to a more harmonious working environment. On a personal level, knowledge of type can be very helpful in counseling (Provost and Anchors, 1987). Carey et al. (1985) use type theory to look at the relationship between communication style and roommate satisfaction. The differences between judging types and perceptive types can often lead to conflicts. What a perceptive sees as a strength in the desire to have complete information or knowledge before proceeding, a judging person often sees as procrastination. And what a judging type sees as decisive action, a perceptive may see as close-minded and precipitate behavior. Differences on the extroversion-introversion and thinking-feeling dichotomies can also lead to problems. From type theory, interpersonal competence is related to extroversion and feeling (Myers and McCaulley, 1998). The focus of extroverts is on people and the external world; that of feeling types is on the effects of their actions and decisions on themselves and others.

In engineering, a great deal of work is done in teams. Clearly, it's important that the members work together harmoniously. A good preparation for this takes place during team projects in undergraduate laboratories and design courses (see Chapter 9). Accounting for type differences and making students aware of each other's different strengths can go a long way toward easing the tension that arises when, say, a perceptive can't put an end to a literature search which his or her judging partner needs for the next day's oral report. Giving and receiving criticism in these situations can also depend on the individual's preferred way of functioning. Whitman and Malzahn (2012) used the more detailed MBTI Step II test to help students learn to assume leadership in engineering teams when the students' skills could contribute significantly to the team.

13.4.4. Student Retention

Retention and attrition are complex issues every college or university must face. Godleski (1987) considers use of the MBTI to increase retention of underachieving college students. His preliminary results showed that there was no difference in extroversion or introversion, but a significantly larger number of sensing over intuitive types and perceptive over judging types who were in academic difficulty. Provost (1991) found type patterns among freshmen experiencing first-year difficulties, with analyses showing overrepresentation of TP combinations. Schurr and Ruble (1988) found that high school performance and the judging preference (J) were the best predictors of college performance. This report was a follow-up to their 1986 study which followed an entire entering college class. McCaulley (1976) describes a study at the Fenn College of Engineering at Cleveland State University comparing first year students who wanted to become engineers and seniors who successfully completed the program. The types in the four corners (the TJ or logical, decisive types) of Figure 13-1 increased their percentage from 45% as freshmen to 55% as seniors. The group showing the greatest loss, from 17.3% as freshmen to 9.2% as seniors, was intuitive-feeling (NF, a pattern more frequently found in the behavioral sciences and communication). McCaulley offers some reasons for these patterns (p. 397):

1. People learn in different ways. If the faculty teaches one way, they will favor some types over others.
2. Faculty members serve as role models for students, but they may not be appropriate models of engineers in industry. Students probably do not realize this.
3. Choice of textbooks and computer-aided learning can favor the learning pattern of some types and cause difficulties for others.

Yokomoto and Ware (1999), who summarized MBTI research in engineering, stated that retention in engineering was highest for students who prefer introversion, thinking and judgment. A more recent study at the University of Tennessee-Knoxville found that SJ types were significantly more likely than SF, NJ, and NF types to graduate in engineering (Parsons et al., 2008). They also found that NF types were significantly less likely to graduate in engineering than SJ, SF, and NJ types. Results from an electricity and magnetism course at Georgia Tech showed that ISFPs specifically and FPs somewhat more generally were most likely to fail the course (Thomas et al., 2000).

Kalsbeek (1987) offers a conceptual model for understanding student attrition. His comment offers an appropriate close to this section: By relating type data to student attrition, educators can consider how different types of students interact with different academic environments and thereby appropriately redesign the curriculum to include teaching styles that will accommodate diverse learning styles (see Chapter 15).

13.4.5. Distributions of Types in Engineering

As Figure 13-1 indicates, all sixteen types are represented in all areas of engineering; however, even the quickest glance reveals that certain types self-select into and are retained very markedly in engineering (McCaulley *et al.*, 1983). For example, the corners of the table are strongly over-represented—what has come to be called the "tough-minded" TJ types. The feeling types (the two inner columns in the type table) are underrepresented with the lowest participation by ENFJ, ESFP, ISFP and INFJ types (In determining this order we took into account that more than 80% of engineering students were male and less than 20 % were female in 1990). McCaulley (1990) raises the question "Are engineering schools preparing their students adequately for the 'people complexities' of the profession?" That feeling types are in such a minority may indicate that the answer is no. Extroverts are also a minority, but the disparity is not as great. These groups tend to drop or transfer out of engineering. Since a great part of engineering work depends on communication and teamwork, it is important that faculty stress the importance of these skills and even teach them specifically (which of course would be appreciated by the extroverted, feeling, and intuitive types).

One speculation worth exploring is whether underrepresented groups in engineering, such as minorities and women, tend to fall into type categories that are only slightly present in Figure 13-1. If it is true, as the data to date indicate, that women classify more as being F than T, this could be part of the reason that they view engineering as "cold" and "unfriendly" (Seymour and Hewitt, 1994). If the ranks of engineering are to be filled in the future, and, as noted in Chapter 1, clearly the standard pool of potential engineering candidates of the past is dwindling, it is these groups that educators will have to look to and encourage. See also Alig (1994) for women majoring in engineering.

Figure 13-1. Distribution of the 16 MBTI Types Among ASEE–MBTI Engineering Students (McCaulley, 1990)

	ISTJ	ISFJ	INFJ	INTJ
Male	17.39	4.19	2.58	9.95
Female	12.22	6.48	3.53	7.07
Aerospace	20.18	4.39	3.51	20.18
Chemical	17.53	4.04	3.37	9.89
Civil	22.87	5.04	1.55	3.88
Computer	11.82	4.93	1.97	7.88
Electrical	19.10	3.64	2.33	12.54
Geological	10.78	2.94	4.90	11.27
Mechanical	16.80	4.44	1.93	10.62
Petroleum	16.30	3.26	0.54	7.07

	ISTP	ISFP	INFP	INTP
Male	6.83	2.45	3.90	9.24
Female	3.24	3.39	4.12	4.86
Aerospace	2.63	0.88	1.75	7.89
Chemical	5.17	1.35	4.49	7.64
Civil	5.81	4.65	2.33	4.65
Computer	3.94	1.48	6.40	6.90
Electrical	5.54	1.60	3.79	10.20
Geological	7.84	2.45	9.31	10.78
Mechanical	9.46	2.32	2.12	6.76
Petroleum	4.89	2.17	5.43	9.24

	ESTP	ESFP	ENFP	ENTP
Male	4.57	2.16	3.16	7.47
Female	2.21	3.24	6.48	7.22
Aerospace	0.88	1.75	3.51	6.14
Chemical	2.25	2.70	4.04	8.54
Civil	4.26	1.94	5.43	2.71
Computer	3.45	2.46	3.45	8.37
Electrical	3.79	1.75	2.04	5.83
Geological	2.45	0.98	2.94	11.76
Mechanical	5.02	2.32	1.54	6.37
Petroleum	6.52	2.17	6.52	7.61

	ESTJ	ESFJ	ENFJ	ENTJ
Male	12.56	2.80	1.71	9.05
Female	13.55	7.22	3.98	11.19
Aerospace	8.77	0.88	1.75	14.91
Chemical	11.01	3.37	1.57	13.03
Civil	20.93	3.88	2.71	7.36
Computer	16.26	7.88	1.97	10.84
Electrical	15.01	2.33	2.19	8.31
Geological	7.35	3.43	3.92	6.86
Mechanical	15.25	3.67	1.35	10.04
Petroleum	10.87	4.89	3.26	9.24

Note: Numbers preceding bar graphs represent the percentage of the sample falling in that type. For example, 17.39% of all male engineers were typed as ISTJ and 20.18% of all aerospace engineers (male and female) were typed as ISTJ.

Engineering students differ from other college students. Compared with a sample group of college freshmen, engineering students are more often introvert, thinking, and judging types (McCaulley et al., 1983). Thus, the E, F and P students are underrepresented. Only on the SN scale were they similar to their peers.

Engineering disciplines attract different types of students (McCaulley et al., 1983). The fields with the highest proportion of extroverts were industrial (56%), computer (55%), petroleum (51%) and mineral (51%). Introverts were more frequent in aerospace (61%), geological (60%) and electrical (59%) engineering. The fields with the highest proportion of the practical sensing types were civil (69%), industrial (61%), mechanical (61%), and mining (60%). Intuitives were frequent in geological (62%), aerospace (60%) and metallurgical (54%). As noted above, all fields had a majority of T types, with the highest proportions in aerospace (82%), electrical (80%), and mechanical (80%). The fields with the lowest proportion of T types were undecided students (68%), geological (69%), computer (69%) and general (70%) engineering.

All types survived to become sophomores, but atypical types had lower retention rates (McCaulley et al., 1983). Judging types were slightly, but significantly, more likely to be retained (entering students were 63% J, retained were 65% J, $p < 0.01$). The practical SJ types were 34% of entering students but were 40% of those remaining. Note that there were no differences in retention between male and female students.

Less typical engineering students, extroverts and feeling types, learn better if given frequent feedback and appreciation; unfortunately, the types who are attracted to the field are the least likely to give such feedback. So it is up to the faculty to teach and model such behavior, which in turn will encourage students to do the same in their own work. Type knowledge can also help in identifying behavioral patterns and needs that may be beneficial in advising students (McCaulley et al., 1983; Lynch, 1987).

13.5. DIFFICULTIES WITH PSYCHOLOGICAL TESTING

The MBTI is prone to the same kinds of problems that plague any psychological test:

1. A student may not understand a question because of phrasing or vocabulary. The MBTI requires at least eighth grade English language skills (the Murphy-Meisgeier Type Indicator is used for grades two through eight). International students occasionally have difficulties taking the MBTI in English.
2. The wrong box may accidentally be marked.
3. Students may mark what they feel they “ought” to think or may try to “psych-out” the tester. Unconscious biases may also affect the results.
4. Current environmental stress may change one’s answers temporarily.
5. Results may be misinterpreted. With the MBTI a little learning can be a dangerous thing, for it’s easy to turn into a parlor game and make it little more than a horoscope reading. Accurate interpretation is assured if a qualified tester is present such as a psychologist, a counselor, or someone certified to administer the MBTI. In particular, the distinct “types” or categories that people are classified in are problematic if any of the scores are near neutral. Scores near neutral should be listed as, for example, S/N or if N is slightly higher N/S. The analysis for dominant and auxiliary functions is unreliable if scores are close to neutral on J–P or I–E scales.

6. Reliability. The MBTI is reliable, but people can change. Times of stress may lead to differing results, and over a period of years growth may be reflected in a change in the reporting of a type preference. However, such changes are expected and predicted within type theory. For example, as one enters middle age, it's common for compensatory development to occur in the less preferred functions (Myers and McCaulley, 1998). Seventy-five percent of people who have retaken the MBTI after one to six years have not changed or have done so in only one category. More information can be found in the reliability studies reported in Chapter 10 of the manual by Myers and McCaulley (1998).
7. Validity. The MBTI has good face validity. The results generally seem true to the test taker. There is also high face validity when one person types another person whom they know well (Carlson, 1989). Does the MBTI measure what it is trying to measure? This is a problem with all psychological tests: What they try to measure is usually based on a psychological theory. Thus, is the underlying theory valid? If it is, does the test accurately measure this? Chapter 11 in the manual discusses more than 100 studies relating to validity.

In addition to the problems common with all psychological tests, as noted earlier, the professional psychology community does not like the MBTI. They quote all the reasons above (with special emphasis on the use of distinct categories), they prefer other tests, plus they probably don't trust the MBTI because the test has been used in many ways by people who are not professional psychologists.

13.6. MBTI MODEL FOR PROBLEM SOLVING

The goals in using the MBTI model of problem solving are to improve the problem solving skills of students and to help them gain respect for others whose minds work differently from their own. The following is a brief and simplified overview of Myers' problem-solving model (Myers, 1991; McCaulley, 1987). The strategy is to use one process at a time and to use it in its own area. Don't, for example, use sensing for seeking new possibilities or feeling to analyze an equipment problem.

1. **Use sensing** (**S**) to face the facts, to be realistic, to find what the situation is, to see your actions, and to see other people's actions. Do not let wishful thinking or sentiment blind you to the realities.
2. **Use intuition** (**N**) to discover all the possibilities, to see how you might change the situation, to see how you might handle the situation differently, and to see how other people's attitudes might change. Do not assume that you have been doing the only obviously right thing.
3. **Use thinking** (**T**) to make an impersonal analysis of the problem; to look at causes and their effects; to look at all the consequences, both pleasant and unpleasant; to count the full costs of possible solutions; and to examine misgivings you may have been suppressing because of your loyalties to others or because you don't like to admit you may have been wrong.
4. **Use feeling** (**F**) to weigh how deeply you care about what your choice will gain or lose; to put more weight on permanent than on temporary effects, even if the

temporary effects are more attractive right now; to consider how other people will feel, even if you think they are unreasonable; and to weigh other people's feelings and your own feelings in deciding which solution will work.

It is likely, and natural, that an individual will choose a solution that appeals to his or her favorite process, but such a solution will be more effective or successful if the facts, possibilities, consequences, and human values are considered. What can go wrong if any of these are ignored? Intuitives may base a decision on some possibility without discovering facts which may preclude the conclusion. Sensing types may settle for a faulty solution because they assume none better is possible. Thinking types may ignore human values. Feeling types may ignore consequences. Thus, what can make the process difficult is that the problem solver is asked to use strengths opposite to his or her own.

Using the attitudes:

1. **Use extroversion** (**E**) to see events in the environment that may influence the problem, to seek people who may have information about the problem, and to talk out loud about the problem as a way of clarifying the ideas.
2. **Use introversion** (**I**) to consider ideas that may have a bearing on the problem, to look for deeper truths that may be obscured by current fads, to think alone deeply about the problem.
3. **Use judgment** (**J**) to stay on track and not be diverted, to plan ahead, and to push yourself and others toward a solution.
4. **Use perception** (**P**) to ensure that you have looked at all aspects of the problem, to watch for new developments, and to avoid jumping to conclusions before all the facts are in.

Yokomoto and Ware (1999) summarized the results obtained on comparison of MBTI characteristics and student learning. The correlation between scores on problem solving exams and homework is higher for sensing students if the exam problems are very similar to the homework, and higher for intuitive students if the exam problems use the same conceptual framework but are different from the homework. Judging types did significantly better in a technical writing class than did perceptive types.

13.7. CONCLUSIONS

The Myers-Briggs Type Indicator offers engineering educators a workable instrument with which to meet the changing needs of engineering education. Measuring preferences as indicated by the students themselves, it is not meant to measure the strength of a trait, as other psychological instruments do. Consequently, it is fairly simple to implement and interpret without requiring a staff psychologist within an engineering department. Attention to differences also makes tremendous common sense as the diverse needs of a new population of students must be met before they can succeed in engineering. We can increase participation in the field as well as increase productivity. Quite possibly, as McCaulley (1990) points out, use of the indicator may help move students toward greater maturity of cognitive development in Perry's model (see Chapter 14, and Felder and Brent (2004)). Finally, to stress that engineering educators must acknowledge that students learn differently, Staiger (1989) concludes: "It would help to have the phrase 'equal opportunity for learning' included in all university admission statements as a constant reminder" (p. 143).

13.8. CHAPTER COMMENTS

There is much to consider in the areas of student types, development, and learning theory. And all interact, thereby further complicating an already difficult equation. In such a complex area, each theory looks only at a small part. The Myers-Briggs Type Indicator offers a starting point for looking at the differences between and among students. More information on the MBTI can be obtained through the following organizations:

- Association for Psychological Type, 9140 Ward Parkway, Kansas City, MO 64114 (www.aptcentral.org)
- Center for Applications of Psychological Type, Inc., 2815 NW 13th St, Gainesville, FL 32609 (http://www.capt.org)
- CPP (formerly Consulting Psychologists Press), 3803 East Bayshore Road, P.O. Box 10096, Palo Alto, CA 94303 (https://www.cpp.com/en/index.aspx)

There are many additional sources available on the internet. We suggest the following:

- The Myers & Briggs Foundation can be accessed at http://www.myersbriggs.org/
- Interesting type descriptions and links can be found at http://www.typelogic.com/
- A free test based on Jung's theories and MBTI is available at http://www.humanmetrics.com

HOMEWORK

1. Consider the process of selecting an adviser for graduate work.
   a. How close a match between student and adviser is necessary?
   b. Which are more important: EI, SN, TF, JP?
   c. How can you figure out the professor's type?
2. Think back to your undergraduate courses. Recall a particular teacher who wasn't fully effective because of a preference for one type over another in his or her approach to teaching. What could this person have done to improve his or her teaching?
3. Determine the dominant, auxiliary, third, and fourth functions for the following types:
   a. ESFJ
   b. ISFJ

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CHAPTER 14

MODELS OF COGNITIVE DEVELOPMENT: PIAGET AND PERRY

In preparing the second edition, we found a limited number of papers in engineering education journals on Piaget's theories. In the past engineering education attracted few students in Piaget's concrete operational period; however, this may be changing. Piaget's theories are also important as background to Perry's theory and necessary background for Chapter 15. There is significant engineering education interest in Perry's theory and the related theories by Belenky et al. and Baxter Magolda.

We will focus on the two theories of development that have been the most influential in the education of scientists and engineers: Piaget's theories of childhood development and Perry's theory of development of college students. To some extent they are complementary as both focus on different aspects of development, and since both Piaget and Perry discuss how students learn, this material ties in with Chapter 15.

These theories are important since they speak to what we can teach students and to where we want students to be when they graduate. Both theories postulate that students cannot learn material if they have not reached a particular level of development. Attempts to teach them material which they are unable to learn leads to frustration and memorization. As engineering students become more heterogeneous, the levels of student development in classrooms will also become more heterogeneous. Thus, it is becoming increasingly important to understand the levels at which different students function.

14.1. SUMMARY AND OBJECTIVES

After reading this chapter, you should be able to:

- Describe Piaget's theory and discuss its implications for engineering education.
- Describe Perry's theory and discuss its implications for engineering education.

- Explain whether you agree or disagree with the specific value judgments in Perry's theory.
- Discuss how the development of men and women may differ. Outline the consequences of this in engineering education.

14.2. PIAGET'S THEORY

Jean Piaget was a Swiss psychologist whose research on the development of children has profoundly affected psychological theories of development and of the teaching of children. His theory has also been widely studied for its application to the teaching of science in grade school, high school, and college. Unfortunately, Piaget's writings tend to be somewhat obscure. We will present a significantly edited version based on secondary sources that focuses on those aspects of his theory that affect engineering education. Further information is available in Flavell (1963), Lawson (1994, 2003), Phillips (1981), Pavelich (1984), and Singer and Revenson (1997). Singer and Revenson (1997) are very useful for teaching Piaget's theory because they use cartoons to explain many of the concepts.

14.2.1. Intellectual Development

Piaget's theory conceives of intellectual development as occurring in four distinct periods or stages. Intellectual development is continuous, but the intellectual operations in the different periods are distinctly different. Children progress through the four periods in the same order, but at very different rates. The stages do not end abruptly but tend to trail off. A child may be in two different stages in different areas.

The *sensimotor* period, which is only of indirect interest to our concerns, extends from birth to about two years of age. In this period a child learns about his or her relationship to various objects. This period includes learning a variety of fundamental movements and perceptual activities. Knowledge involves the ability to manipulate objects such as holding a bottle. In the later part of this period the child starts to think about events that are not immediately present. In Piaget's terms the child is developing meaning for symbols.

The *preoperational* period lasts from roughly two to seven years of age. Piaget has divided this stage into the preoperational phase and the intuitive phase. In the preoperational phase children use language and try to make sense of the world but have a much less sophisticated mode of thought than adults. They need to test thoughts with reality on a daily basis and do not appear to be able to learn from generalizations made by adults. For example, to a child riding a tricycle the admonition "Slow down, you are going too fast" probably has no effect until the child falls over. This continual testing with reality helps the child to understand the meaning of "too fast." Compared to adult thinking, the thinking of a child in the preoperational phase is very concrete and self-centered. The child's reasoning is often very crude, and he or she is unable to make very simple logical extensions. For example, the son of one of the authors was astounded when he heard that his baby sister would be a girl when she got older!

In the intuitive phase the child slowly moves away from drawing conclusions based solely on concrete experiences with objects. However, the conclusions drawn are based on rather vague impressions and perceptual judgments. At first, the conclusions are not put into words and are often erroneous (and amusing to adults). Children are perception-bound and often very rigid in their conclusions. Rational explanations have no effect on them because they are unable to think in a cause-and-effect manner. During this phase children start to respond to verbal commands. It becomes possible to carry on a conversation with a child. Children develop the ability to classify objects on the basis of different criteria, learn to count and use the concept of numbers, and start to see relationships if they have extensive experience with the world.

At around age seven (or later if the environment has been limited) the child starts to enter the *concrete operational* stage. Age seven is the time period when the frontal lobes of the brain develop (Lawson, 2003). In this stage a person can do mental operations but only with real (concrete) objects, events, or situations. He or she can do mental experiments and can correctly classify different objects (apples and sticks, for example) by some category such as size. The child understands conservation of amounts. This can be illustrated with the results of one of Piaget's experiments (Pavelich, 1984). Two identical balls of clay are shown to a child who agrees they have the same amount of clay. While the child watches, one ball is flattened. When asked which ball has less clay, the preoperational child answers that the flattened ball has less clay. The concrete operational child is able to correctly answer this question. He or she becomes adept at addition and subtraction but can do other mathematics only by rote. In the concrete operational stage children also become less self-centered in their perceptions of the universe. Logical reasons are understood. For example, a concrete operational person can understand the need to go to bed early when it is necessary to rise early the next morning. A preoperational child does not understand this logic and substitutes the psychological reason, "I want to stay up."

Concrete reasoning used in engineering courses includes (Koretsky et al., 2012):

1. *Seriation and classification*. Use of an abstract characteristic to classify and order objects (e.g., types of pumps based on maximum flow rate).
2. *Transitivity and reversibility*. Students can do algebraic manipulation and determine logical relations between variables (e.g., if $y = Ax + b$, solve for x. If Jack is taller than Mary and Mary is taller than Bob, is Jack taller than Bob?).
3. *Conservation*. Students can do conservation of mass problems. Since energy terms are more abstract, concrete operational students have more difficulty with energy balances.

Piaget thought that the concrete operational stage ended at age eleven or twelve. There is now considerable evidence that these ages are the earliest that this stage ends and that many adults remain in this stage throughout their lives. Approximately 30 to 60% of adults are in the concrete operational stage or are in a transition region between concrete and formal operations (Pintrich, 1990). Thus, many college freshmen are concrete operational thinkers or in the transition region; however, the number in engineering is small and is probably less than 10% (Pavelich, 1984). For reasons that will become clear shortly, concrete operational and transition thinkers will have difficulty studying engineering. However, they can be fully functioning adults. Piaget's theories at the concrete and formal operational stages measure abilities only in a very limited scientific, logical, algebraic sense. A person may be a successful hard worker, a good, loving parent and spouse, and a good citizen, but be limited to concrete operational thought.

The final stage in Piaget's theory, the *formal operational* stage, may start as early as age eleven or twelve, but often starts later. A formal operational thinker can do abstract thinking and starts to enjoy abstract thought. This person becomes inventive with ideas and starts to delight in such thinking. He or she can formulate hypotheses without actually manipulating concrete objects, and when more adept can test the hypotheses mentally (Phillips, 1981). This testing of logical alternatives does not require recourse to real objects. The formal operational thinker can generalize from one kind of real object to another and to an abstract notion. In the experiment with the balls of clay, for example, the formal thinker can generalize this to sand or water and then to a general statement of conservation of matter. This person is capable of learning higher mathematics and then applying this mathematics to solve new problems. When faced with college algebra or calculus the concrete operational thinker is forced to learn the material by memorization but then is unable to use this material to solve unusual problems. The formal operational thinker is able to think ahead to plan the solution path (see Chapter 5 for discussion of problem solving) and do combinatorial thinking and generate many possibilities. Finally, the formal operational person is capable of metacognition, that is, thinking about thinking. Students who use metacognition know their level of understanding of topics.

Formal operations used in engineering and science courses (Koretsky et al., 2012) are listed below:

1. *Proportional reasoning* includes manipulation of linear equations. Because they practice this type of reasoning in high school, many students in the transition range are comfortable with simple applications of proportional reasoning. However, they probably struggle with understanding log-log and semi-log plots.
2. *Probabilistic reasoning* involves dealing with statistics and population distributions instead of discrete numbers. Students will not become skilled until they are forced to practice this type of reasoning.
3. *Propositional reasoning* occurs in ethics and in decision-making. Students need practice applying logic in decisions (e.g., with a Kepner-Tregoe decision matrix, Table 4-2) and in ethics (see Section 12.4).
4. *Combinatorial reasoning* is used to determine all possible ways to run an experiment or to change the independent and dependent variables in a problem. Students who have not developed this ability are surprised when different dependent variables are selected on a test.
5. *Separation of variables* is a necessary skill to determine the individual effect of variables. Running control experiments is one approach to separating the effects of variables.

Students in the transitional region between concrete and formal operations may be comfortable with one or more of these operations, but not the others. They may realize that in particular courses (e.g., math and engineering) abstract thinking is necessary. However, they have not generalized formal operational processes to all areas of their life. This domain specificity of many students is one of the major criticisms of Piaget's theory (Pintrich, 1990).

When asked to solve a problem involving a formal operation that has not been exercised sufficiently, most people immediately revert to the concrete operational stage. They want to manipulate objects and numbers. Instead of fighting this normal desire, instructors should initially do an example with concrete objects and real numbers. Then generalize the specific result to a more abstract and general analysis. For example, distribution functions can be introduced by listing the heights of all students in the course. Then after generating this distribution, the instructor can see if the data fits a theoretical distribution such as the normal distribution. Since the students who have already mastered probabilistic learning will probably do the generalization one or two steps ahead of the instructor, they have practice constructing knowledge. This particular example could become quite interesting if there are large numbers of students from two countries with different average heights. Even if the distribution of heights in each country follows a normal distribution, the sum of the two distributions will not be a normal distribution—a fairly subtle point that is a good test of understanding distributions.

Lawson (2003) postulates that there is an additional level of scientific thinking (called level 5) past Piaget's formal operational stage. In the formal operational stage an adept person can formulate and test hypotheses involving observable causal agents without actually manipulating the objects. In level 5 the person can formulate and test hypotheses involving unobservable entities. Lawson believes that this skill is important in science. He tested college students who passed the normal test of Piagetian formal operational stage (developed earlier by Lawson, 1994) for the level 5 skill. The level 5 tests predicted grades in science courses. Lawson's level 5 has not percolated into engineering education yet.

14.2.2. Application of Piaget's Model to Engineering Education

Engineering education requires formal operational thought. Engineering students in the transitional phase appear to be able, with considerable work, to survive in engineering. This probably occurs because:

1. They have learned that formal operational thought processes must be used in their engineering courses. When problems require formal processes that they know how to use (e.g., proportional reasoning), they use these methods.
2. When they cannot use appropriate formal operations, their answers based on substitution of concrete operations and rote learning have earned enough partial credit to obtain passing grades.
3. High grades in other courses may compensate for low engineering grades.

At selective schools there are a relatively small number of engineering students in the transitional phase and probably none in the concrete operational stage. They will have difficulties in engineering and many will drop out. These students may make it through the curriculum by rote learning, partial credit, doing well in lab, repeating courses, and so forth. Concrete operational students can be identified by repeated administration of tests with novel problems on the same material (Wankat, 1983). On the first few tests students may be unable to work the problem either because of lack of knowledge or because of an inability to solve abstract problems. On the basis of a single test it is difficult to tell if lack of knowledge or poor problem-solving ability has caused the difficulties. Students who can use formal operational thinking learn from their mistakes, learn the missing knowledge, and fairly rapidly become able to solve difficult new problems. Students who are in the concrete operational stage do not appear to be able to learn from their mistakes on problems requiring formal operations, making the same mistakes over and over. The solutions of these students do not appear to follow any logical pattern since they often just try something (anything) to see if it works and to see if they get any partial credit. These students have great difficulty in evaluating their solutions. Concrete operational students will often try to cope with engineering courses by building a catalog of example solutions and then using pattern recognition to solve problems—essentially rote learning (Koretsky et al., 2012). Since concrete operational students may try hard but still have great difficulty in understanding abstract logic, the use of words like "obviously," "clearly," or "it is easy to show" by the professor is frustrating and demotivating to them. In engineering, concrete operational students are likely to be quite frustrated and frustrating to work with.

In schools with open enrollment there may be a number of students in the concrete operational and transition stages. Cinquepalmi et al. (1985) found that the Piagetian test [Lawson's test of Scientific Reasoning (Lawson, 1994) is a well-accepted paper and pencil test to determine Piagetian level] was the best single predictor of which students would perform adequately in engineering studies. Dropout rates after 1.5 years ranged from 66% to 30% as students cognitive development stage went from concrete to formal.

The transition to formal operations can be aided by (Cinquepalmi et al., 1985):

1. Handling real objects and experimental apparatus
2. Collecting data and organizing it in tables and graphs
3. Interpreting the data
4. Determining concepts and relationships based on the data

The suggestion has been made repeatedly that freshmen-sophomore courses in engineering should be made available for non-engineering students. If this were done, the much higher percentage of concrete operational students in the general student population would require significant changes in the content and teaching methods.

Piaget's theory is also useful for students who made the transition to formal operations before they came to college. They probably have had little experience with some of the formal operations listed earlier. All courses can work on combinatorial reasoning by challenging the students to think of all the ways problems using the same equations can be posed. If this is mentioned as a method of guessing what will be on the test, students will be motivated to try it. We believe that all engineers should be required to take a probability and statistics course that focuses on understanding the principles. In terms of Piaget's formal operations this means the students learn to use probabilistic reasoning. Combinatorial reasoning should also be enforced in this course. Do the detailed statistical calculations the way they are done in industry—with commercial software.

Even students with high grades often need to practice propositional reasoning. For example, most engineering students have difficulty determining what item in the code of ethics supports a particular action as being ethical (see Section 12.4). In a debate they should be able to back the argument of either side with logical arguments, and, most importantly, they need practice judging the arguments. Many students also have difficulty making rational decisions and need to practice and receive feedback. Even a single class session on decision methods can make a difference. Students can practice separation of variables in laboratory courses and research projects.

14.2.3. Piaget's Theory of Learning

The presence of some concrete operational students in engineering leads us naturally to the question of how a student moves from one stage to another. Piaget postulates that there are *mental structures* that determine how data and new information are perceived. If the new data make sense to the existing mental structure, then the new information is incorporated into the structure (*accommodation* in Piaget's terms). Note that the new data do not have to exactly match the existing structure to be incorporated into the structure. The process of accommodation allows for minor changes (figuratively, stretching, bending and twisting, but not breaking) in the structure to incorporate the new data. If the data are very different from the existing mental structure, it does not make any sense to incorporate them into the structure. The new information is either *rejected* or the information is *assimilated* or *transformed* so that it will fit into the structure. Brain research has shown that learning actually changes the brain structure and the connections between neurons (Leamnson, 2000).

A concrete person will probably reject a concept requiring formal thought. If forced to do something with the data he or she will memorize even though the meaning is not understood. This is similar to memorizing a passage in a foreign language that one cannot speak. An example of transformation is a person's response to seeing a pink stoplight. Everyone "knows" that stoplights are red, and thus the pink stoplight will probably be registered as being red since red stoplights fit one's mental structure.

How does one develop mentally? How does one make the quantum leap from concrete to formal thinking? Mental development occurs because the organism has a natural desire to operate in a state of equilibrium. When information is received from the outside world that is too far away from the mental structure to be accommodated but makes enough sense that rejecting it is difficult, then the person is in a state of *disequilibrium.* The desire for equilibration is a very strong motivator to either change the structure or reject the data. If the new information requires formal thinking and the person is otherwise ready, then a first formal operational structure may be formed. This formal operational structure is at first specific for learning in one area and is slowly generalized (the person is in a transitional phase). The more often the person receives input that requires some formal logic, the more likely he or she is to make the jump to formal operational thought. Since this input takes place in a specific area, the transition to formal operations often occurs first in this one area. Also, a person with a less rigid personality structure and tolerance for ambiguity is probably more likely to make the transition. We emphasize that the transition to formal operations may not be easy.

Piaget developed a variety of experiments to test what stage children were in and to help them make the transition to the next stage. Unfortunately, the experiments work well for testing the stage but not for moving people to the next stage. A method called the *scientific learning cycle* has been developed to help students in their mental development (see Section 15.2.2). In the scientific learning cycle the students are given firsthand experience, such as in a laboratory with an attempt to cause disequilibration. The instructor then leads discussions either with individuals or in groups to introduce terms and to help accommodate the data and thus aid equilibration. Finally, students make further investigations or calculations to help the changed mental structure fit in with the other mental structures (organization). The scientific learning cycle helps people move to higher stages, but progress is very slow. Callahan et al. (2011) reported small, but statistically significant increases, in Piagetian formal reasoning skills for first year students in a course on Scientific Thought and Reasoning. The students had tested as not calculus ready, which is often a signal for students in the concrete operational stage. With special courses appropriate for their developmental needs, college students who did not transition into the formal operational stage earlier can make progress, albeit slowly.

The scientific learning cycle is also useful for working with students who are already in the formal operational stage since these students also learn by being in a state of disequilibrium and using accommodation. The scientific learning cycle is discussed in more detail in Section 15.2.2.

Piaget's theory has partially withstood the test of time and partially been modified (Kurfiss, 1988). It is now generally agreed that individuals actively construct meaning. This has led to a theory called constructivism, which is discussed in more detail in Chapter 15. Piaget's general outline of how people learn and the need for disequilibrium has been validated. Disagreements with Piaget focus on the role of knowledge in learning. More recent researchers have found that both specific knowledge and general problem-solving skills are required to solve problems, while Piaget did not recognize the importance of specific knowledge.

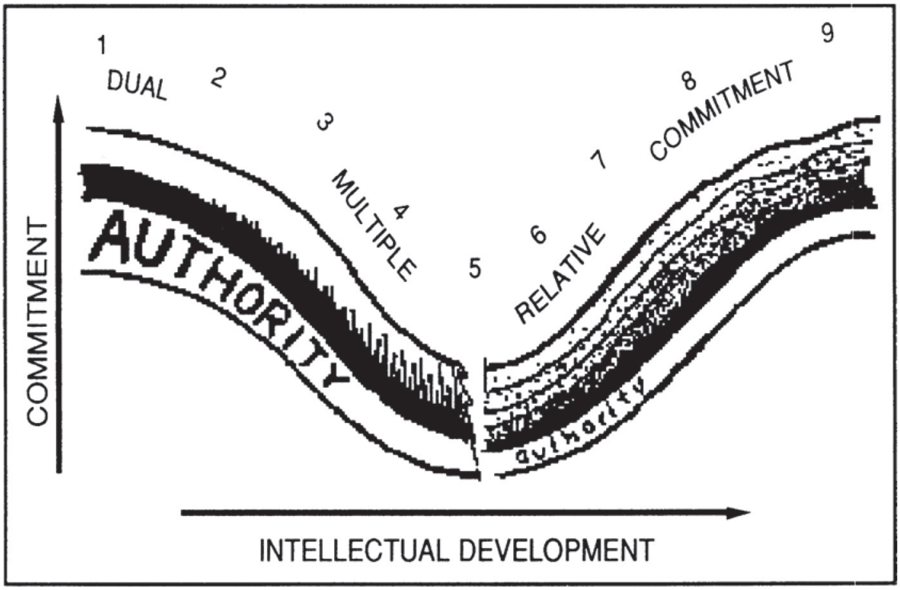
14.3. PERRY'S THEORY OF DEVELOPMENT OF COLLEGE STUDENTS

William G. Perry, Jr., studied the development of students at Harvard University through their four years at the university. His team used open-ended interviews as the technique of measurement. Over a period of years a pattern of development could be distinguished among all the varied responses of the students. Perry then used this pattern of development to rate another group of students. This replication showed that the scheme was reproducible at least for the men at Harvard University. Since publication of the results (Perry, 1970), interest in Perry's theory of development during the college years has grown. His book was called "the most influential book of the past twenty years" on how college students respond to college (Eble, 1988).

Pioneering studies that open up new areas for research always end up being criticized later. First, Perry's study has been criticized since the group studied was quite homogeneous and consisted mainly of young men from privileged backgrounds. Additional studies since 1970 (Hofer and Pintrich, 1997) have essentially duplicated Perry's results and shown that his scheme has fairly general validity except that extensive modifications need to be made for the development of many women (Belenky et al., 1986, 1997). Baxter Magolda (1992) studied both men and women and showed that the patterns observed previously by Perry (1970) and Belenky et al. (1986) occurred in both genders although there are gender preferences. Cross-cultural studies are just beginning (Zhu and Cox, 2012). Second, the original study by Perry (1970) did not include classroom teaching and learning (Hofer and Pintrich, 1997). King and Kitchener (1994) developed a reflective judgment model that attempts to explain how people understand knowing and solution of ill-structured problems. Schommer (1990) studied college students and documented relationships between beliefs about knowledge, the strategy used, and performance. Hofer and Pintrich (1997) compared these models and synthesized their agreements into a four-compartment model that shows individuals construct a personal theory about the nature of knowledge and the process of knowing. A more recent model that builds on Perry's model is the reflective judgment model (King and Kitchener, 1994). Felder and Brent (2004a) compared the models and illustrated their similarities. Third, Perry's model relied on extensive interviews instead of easily used paper and pencil tests. Paper and pencil tests were developed by Schommer (1990), Baxter Magolda (1992) and Carberry et al. (2010) for the lower levels of Perry's model. The paper and pencil tests appear adequate but rate individuals lower than interviews.

It would be convenient if Perry's scheme started where Piaget's theory stops. Chronologically, the two theories do fit this way, but in other more important ways the theo-

Figure 14-1. Perry's Model of Intellectual Development (Culver and Hackos, 1982. Copyright 1982, ASEE. Reprinted with Permission)



ries are *not* a match. Perry does use Piaget's ideas of how students learn. That is, a certain amount of disequilibration is necessary for accommodation to occur. However, Perry's theory, unlike Piaget, is not concerned with problem solving and the applications of logic. Briefly stated, Perry's model is concerned with the changes in students' epistemology, their belief systems about knowledge and how one knows. Perry studied how students move from a *dualistic* (right versus wrong) view of the universe to a more *relativistic* view, and second, how students develop commitments within this relativistic world. There is a strong learning connotation in Perry's model. Similar to Piaget's theory, students cannot understand or answer questions that are in a developmental sense too far above them.

14.3.1. Positions in Perry's Model

From his interviews and by extrapolation Perry (1970) postulated nine *positions* as shown in Figure 14-1. These positions and the movement from position to position represent the major contribution of Perry's model.

Position 1: Basic Duality. The person sees the world dualistically, right versus wrong. There are no alternatives. Authorities know all the answers. Men appear to identify with the authority figure while women do not (Belenky et al., 1986, 1997). The teacher as an authority is supposed to teach the correct answers to the students. Failure to do so means that the teacher is a bad teacher. Hard work and obedience will be rewarded. Authority is so all-knowing that all deviations from authority are lumped together with error and evil. Perry (1970) notes that this position is basically naive since there is no alternative or vantage point that allows the person to observe her- or himself.

Perry (1970) talked to freshmen after one year at Harvard. He did not talk to anyone in position 1 but inferred this position from student reports about what they had been like when they entered Harvard. Perry notes that this position's assumptions are incompatible with the culture of pluralistic universities and thus students will be unable to maintain this position if they stay at the university. Much of the confrontation with pluralism occurs in residence halls, which may be a good reason to strongly encourage freshmen to live in residence halls. Many other studies (e.g., Moffatt, 1989) have reaffirmed the importance of residence halls in the development of students. Students may start in this position because of a culturally homogeneous or narrow environment, but they will quickly lose their innocence at a university.

Confrontations with their basic dualistic position both in class and in residence halls cause disequilibration. The student tries to accommodate the new ideas of multiplicity. This can be done by moving to position 2 or, at least temporarily, by modifying position 1. The modified position 1 assumes that absolute truths exist, but that authorities may not know what these truths are. Thus conflicts are explained since authority doesn't know the truth, but if one searches hard enough there is an absolute truth. This modified position itself leads to position 2 since the modified position admits that authorities can make errors. Unfortunately, there is another possible outcome to the stress induced by confronting multiplicity at the university. The student may leave.

In their study of the development of women, Belenky et al. (1986, 1997) included individuals from many social classes. By talking to women in social service agencies, they detected the presence of a position before (or below) position 1, which they called "silence." These women were from very deprived or abusive backgrounds. "Silent" women were unable to understand the words of others and were unable to articulate their own thoughts and feelings. With the steady increase in older students returning to college, some women who have once been in this position will become engineering students.

Position 1 is also the home of intolerance and bigotry, the position taken by some cults. Although engineering educators tend to shy away from moral arguments, there seem to be clear moral reasons to help students move out of position 1 into position 2.

People who are in higher level positions can display intolerance and bigotry on certain issues. Apparently, when these issues arise the person temporarily reverts to position 1. An example in engineering is that of lesbian, gay and bisexual (LGB) students in engineering—an issue that was first studied in 2009 (Cech and Waidzunas, 2009). Cech and Waidzunas found a clear heterosexual/homosexual dualism in engineering. The typical belief was that heterosexuals belong in engineering but homosexuals do not. Combating these beliefs will be difficult if students are in positions 1 or 2. Students in higher positions who critically examine their beliefs will often be able to change them. Faculty can help by encouraging or requiring critical examination of beliefs.

Moving past stage 1, sorting out the differences between the different Perry stages and the differences between different developmental patterns can be challenging. The summary shown in Table 14-1 (Felder and Brent, 2004a) can be very helpful.

Position 2: Dualism; Multiplicity Prelegitimate. In position 2 the student can perceive that multiplicity exists but still has a basic dualistic view of the world. There is a right and a wrong. Multiple views or indications that there are "gray" areas are either wrong or interpreted as authority playing games. Since it is possible for authority to be wrong, the absolutes are sepa-

Table 14-1. Summary of Models of Intellectual Development (Copyright ASEE, 2004. Reprinted with permission from Felder, and Brent, 2004a)

	Absolute Knowing[a]		Transitional Knowing[b]		Independent Knowing[c]		Contextual Knowing[d]
Baxter Magolda	Mastery Pattern	Receiving Pattern	Impersonal Pattern	Interpersonal Pattern	Individual Pattern	Interindividual Pattern	
Perry	2 Late Dualism	—	3 Multiplicity Subordinate	—	4 Multiplicity	—	5–7 Contextual Relativism Preliminary Commitment
Belenky (Women's Ways of Knowing)	—	Received Knowledge	—	Subjective Knowledge	Procedural Knowledge: Separate Pattern	Procedural Knowledge: Connected Pattern	Constructed Knowledge
King–Kitchener	Early Prereflective Thinking		Late Prereflective Thinking		Quasi-Reflective Thinking		Reflective Thinking

a Absolute knowing. All knowledge that matters is certain; all positions are either right or wrong. Authorities have The Truth and the responsibility to communicate it, and the students' job is to memorize and repeat it. Mastery pattern (more men than women): Students raise questions to make sure their information is correct and challenge deviations from their view of the truth. Receiving pattern (more women than men): Students take in and record information passively, without questioning or challenging it.

b Transitional knowing. Some knowledge is certain and some is not. Authorities have the responsibility to communicate the certainties, and the students are responsible for making their own judgments regarding the uncertainties. Impersonal pattern (more men than women): Make judgments using a logical procedure prescribed by authorities. Full credit is deserved for following the right procedure, regardless of the clarity of the reasoning and the quality of the supporting evidence. Interpersonal pattern (more women than men): Base judgments on intuition and personal feelings; distrust logical analysis and abstract reasoning.

c Independent knowing. Most knowledge is uncertain. Students take responsibility for their own learning rather than relying heavily on authorities or personal feelings. They collect and use evidence to support judgments, but often superficially, and believe that when knowledge is uncertain all conclusions regarding it are equally good if the right procedure is used to reach them. Individual pattern (more men than women): Rely on objective logic, critical thinking, and challenging their own and others' positions to establish truth and make moral judgments. Interindividual pattern (more women than men): Rely on caring, empathy, and understanding of others' positions as bases for judgments.

d Contextual knowing. All knowledge is contextual and individually constructed. Students take responsibility for making judgments, acknowledging the need to do so in the face of uncertainty and ambiguity. They use all possible sources of evidence in the process—objective analysis and intuition, their own thoughts and feelings and ideas of others whose expertise they acknowledge—and they remain open to changing their decisions if new evidence is forthcoming.

rate from authority. Thus, some authorities are smarter than others. This position may lead to the feeling that "I am right and authority is needlessly confused." The person may hold the view that there is one answer, but authority shows multiple answers as a game to make students learn how to find the one right answer.

An engineering student in position 2 can successfully solve problems, particularly closed-end problems, with a single right answer. These are the types of problems students in position 2 expect, and these students prefer engineering classes to humanities classes because the problems fit their dualistic mode of thought. In design classes, where problems have multiple answers, these students have difficulties, and they protest against open-ended problems. A student in position 2 wants the teacher to be the source of correct knowledge and to deliver that knowledge without confusing the issues. In this student's view a good teacher presents a logical, structured lecture and gives students chances to practice and demonstrate their skills. From the student's viewpoint a fair test should be very similar to the homework.

Perry notes that students are bewildered and protest as they move from position 1 to position 2. The move from position 1 to position 2 may appear to be small; however, the student has made a major concession by allowing for some complexity and some groping into uncertainty.

In the two dualistic positions men and women use language differently. In general, men tend to talk and women listen. Since listening to authorities is the primary focus of women in the dualistic positions, Belenky et al. (1986, 1997) call these positions "received knowledge."

Position 3: Multiplicity Subordinate or Early Multiplicity. In position 3 multiplicity has become unavoidable even in hard sciences and engineering. There is still one right answer, but it may be unknown by authority. Thus the gap between authority and the one truth has been widened. The student realizes that in some areas the knowledge is "fuzzy."

This position has some built-in procedural conflicts. If authority does not yet know the answer, how can the professor evaluate the student's work? This is a considerable change from position 2 where honest hard work would presumably lead to the correct answers. Now, in position 3 honest hard work is no longer guaranteed to produce correct answers, and thus good grades seem to be based more on "good expression." The big question students ask is "What do *they* want?" The methods for evaluation become a very important issue and students want the amount of effort put into something to count. From the students' perspective a good professor presents very clearly defined criteria for evaluation and clearly explains the methods used for determining the right answer even if he or she does not (temporarily) know the right answer.

For men, education appears to play a significant role in the shift to multiplicity. From a developmental sense, one problem with engineering education is that there are few challenges at the lower levels to move the student into position 3 or 4. In class the challenges of multiplicity usually come in senior design classes and in graduate school. The lower-level classes are usually taught as if everything is known. This can lead to severe stress for students in a design course where multiple answers are expected and they are suddenly expected to function in a world with multiple answers. Students survive design courses but often do so without changing a great deal. This survival may occur because design is an isolated class that lasts for one or two semesters, and the legitimacy of multiplicity may not be reinforced in other classes or in the rest of the student's life. In addition, students who are academically very good can often hide from the challenges of multiplicity through competence (their design is likely to have fewer technical errors and they receive good grades). Beginning graduate students often become very frustrated as they try to determine what they are supposed to do. With less structure, fewer supports, a longer-term reward compared to seniors, and more pressure to adjust to a world of multiplicity, the graduate student's frustration is understandable. Graduate work in engineering and the physical sciences is similar to undergraduate work in the humanities in the respect that both confront the student with multiplicity and uncertainty.

For most women formal education is relatively unimportant for the shift into "subjectivism" [the term used by Belenky et al. (1986, 1997) for multiplicity]. They shifted into subjectivism "after some crisis of trust in male authority in their daily lives, coupled with some confirmatory experience that they, too, could know something for sure" (Belenky et al., 1986, p. 58).

Position 4: Complex Dualism and Advanced Multiplicity. The student tries to retain a dualistic right-versus-wrong position but realizes that there are areas of legitimate uncertainty and diversity of opinion. Students react to position 4 in one of two ways. They may conform to what authority seems to want and learn the forms of independent intellectual thought. These students learn that *independent-like* thought will earn them good grades. Genuinely independent thought has not yet been achieved or even considered as an issue. Most of the students Perry studied took this route. However, learning the forms is not enough, and these students may be tempted to *escape*.

The second reaction is that the student may oppose what authority wants in areas where multiplicity is important. The student may raise this multiplicity of opinions to a pervasive viewpoint that "anyone has a right to their own opinion." This raises areas of multiplicity and uncertainty to equal status with areas of dualism. "Everyone has a right to their own opinion" is obviously a wonderful position from which to fight authority. The danger of this position is that a bland "anything goes" attitude may prevail. The student may refuse to think, since he or she believes everything can be solved by intuition. Men in this position fight authority openly, while women fight authority internally as "hidden multiplists" (Belenky et al., 1986, 1997). These women may be silently alienated from college. Since engineering does not affect their interior life, engineering may appear irrelevant and they may quit engineering even though they have good grades. This position was taken by fewer students and is probably rare in engineering.

An engineer in position 4 can solve problems cleverly and creatively. The task of solving the problems becomes a game, but he or she cannot see that some problems are much more important than others. This person lacks vision and may solve problems considered unimportant or even immoral by others. Many engineering graduates with both baccalaureate and advanced degrees seem to be in positions 3 and 4.

Position 5: Relativism. In position 5 a person sees everything as relative, not because authority wants it that way but because that is the way he or she sees the world. There is a revolutionary switch from position 4 to position 5. In position 5 relativism becomes the common characteristic of everything and absolutes are a special case. One must then determine if complexity is *not* necessary. In position 4 the situation was the reverse: Dualism was the general principle, and relativism was a special case useful for certain classes of problems. Perry noted that this is often an extremely quiet revolution and that students hardly notice that it has occurred. The relativistic thought process becomes habitual without being noticed. Students who focus heavily on engineering or science, may experience shock when they realize that everything is relative in advanced classes.

Perry saw this position as occurring in three subpositions. First, the person divides the world into a relativistic area and into a dualistic area where authority still has answers. Then, the whole world is seen as relativistic, but this position alternates with a dualistic position. Finally, the whole world is seen as relativistic.

The relativistic position can be a very powerful one. There is room for detachment and objectivity. One can think previously forbidden thoughts. This ability to stand outside the situation and think objectively may, in Perry's words, "rank with language as the distinctive triumph of the human mind." The person in the relativistic position can get beyond the statement "all opinions are equal" by using the laws of evidence to develop positions that are more likely.

Belenky et al. (1986, 1997) noted that men and women may use different logical procedures in position 5, which they called "procedural knowledge." Most men and some women use the traditional logical approach with objective analysis and argument to form opinions. This *separate knowledge* or *objective knowledge* (Palmer, 1983) purposefully removes the person's personal experiences and feelings from the logical analysis. Objective knowledge emphasizes doubting and argument. It is the method one would expect from thinking types on the MBTI (Chapter 13), and it corresponds to the usual engineering approach. Arguments are supposed to be between positions, but many women and some men have difficulty separating positions from people. They use an approach called *connected knowledge*, which is an empathic treatment of divergent views. Connected knowledge personalizes knowledge and attempts to understand the reasons for another's way of thinking. Belief, not doubt, that the other is right from his or her viewpoint is the key stance of connected knowledge. Both feelings and thought are important. Connected knowledge would be expected of Myers-Briggs feeling types who are in position 5. In the same way that everyone has both feeling and thinking capabilities, everyone has the potential to learn both objective and connected knowledge. Individuals who strongly prefer to use connected knowledge as a way of understanding may find the environment at an engineering college somewhat hostile—since only objective knowledge is taught. Because these individuals can make major contributions as engineers (e.g., in life cycle design or conflict resolution), it is important to accommodate them in the educational system. For women the presence of a benign and encouraging authority appears to facilitate movement into position 5.

From the student's viewpoint in position 5 a good instructor acts as a source of expertise, but does not know all the answers since many answers are unknowable. This professor helps students become adept at forming rules to develop reasonable and likely solutions or solution paths. It is important for the professor to show that good opinions are supported by reasons. The student has become much more comfortable with being evaluated in a relativistic world and realizes that the evaluation is of her or his work and not of her or him.

There are problems in position 5. The world is full of possibilities, and there does not appear to be a clear way to choose. Decisions made earlier are now called into doubt. The student wonders whether engineering really is the right choice. Did he or she choose the best college? And so on. Position 5 then represents both a period of strength and possibilities and a period of doubt and loneliness. Assuming that a person is eventually going to move into position 5, it is probably better to do so early while many important career and life decisions have yet to be made. Position 5 can also appear "cold" and even sinister to others because of the focus on method and the dissociation between means and values.

Position 6: Relativism: Commitment Foreseen. The way out of the uncertainty of relativism is *commitment.* In position 6 the student can see the need for commitment but has not yet made the commitment. This need for commitment may be seen as a logical necessity (this is likely for people who are a *T* on the MBTI or may be felt (people who are an *F*). Commitment may be looked forward to with eagerness, or the person may fight commitment. People who fight commitment may stay uncomfortably in position 5, or may escape or retreat (discussed later).

Most students think they have already made firm commitments. Perry uses Commitment (with a capital C) to have a special meaning. It is a mature decision made after one has accepted that the world can be viewed as relativistic and has seen all the possibilities. Previous decisions have been called into doubt and looked at from a detached viewpoint. The new Commitment may be the same decision made previously, but the Commitment is deeper. Commitments can be made in a variety of areas such as career, religion, marriage, politics, values, and so forth. The Commitments one makes help set the person's identity and style. At this point one makes a decision by objective or connected knowledge on how much of the past to reject and how much to retain. This shedding of parts of the past is clearly different from adolescent rebellion, which tends to be mindless.

In position 6 the person can see this need for Commitment, but the Commitment has not yet been made. People who move forward into position 7 often do so in one area of their lives at a time. They remain in position 6 in other areas.

For an engineering student who has invested a great deal of time in studying engineering, going through position 5 can be very unsettling. Position 6 can be something of a relief since the student sees that it is all right to commit to engineering if that is a good decision. However, a major Commitment is not to be rushed, and the person may stay in position 6 for a while.

Positions 7 through 9: Levels of Commitment. Positions 7 through 9 are all levels of Commitment starting with initial Commitment in position 7. These positions represent degrees of development and depth of Commitment and are not as clearly defined as are the other positions. The person moves from position 6 into position 7 in one area by making a Commitment of his or her own free will. For some this is risky and may be done tentatively in relatively safe areas. As the person becomes more comfortable with making Commitments, he or she makes them in areas that are not as safe, eventually finding not only that a series of finite, discrete decisions have been made, but that a way of life has been developed.

Perry sees the student in position 7 first taking responsibility for who he is or will be in some major area of his life ("I'll stay in engineering"). In position 8, stylistic issues of Commitment become important "If I am going to be an electrical engineer, how will I do it?" "What will my specialties be?" "What degrees should I get?" And so forth. Position 9 is a postulated position of maturity where the person has developed a sense of self in both Commitments and style. Positions 7 to 9 are usually lumped into a single position of Commitment. Perry postulated that this is a position reached sometime after graduation. Women also make a commitment, but it is to a life rather than the single Commitments men often make (Belenky et al., 1986, 1997).

Belenky et al. (1986, 1997) added insight into the thought processes of the Commitment positions. The thought process uses *constructed knowledge* where procedural knowledge gained from others is integrated with personal or "inner" subjective knowledge based on personal experience and introspection. This constructed knowledge allows the individual to integrate thought and feeling and avoid the compartmentalization that Belenky et al. (1986, 1997) perceive as a shortcoming of objective knowledge. At the levels of Commitment a good instructor provides freedom so that students can learn what they need to learn. The instructor also needs to forge linkages within the class (Palmer, 1983).

Perry's model is a staged model that tends to ignore the situational specificity of behavior and knowledge. Real people in real situations have the annoying tendency to be complex. They don't fit into one stage, but depending upon the situation may be in several different stages. Despite this difficulty, Perry's model is a very useful model for conceptualizing the development of college students. Understanding Perry's model will provide faculty with greater empathy for students struggling to cope with college (Moore, 1994). After finishing this section on the stages in intellectual development, we suggest you return to Table 14-1 to check your understanding.

14.3.2. Alternatives to Growth

Perry hypothesizes that natural growth is from position 1 toward position 9. At Harvard he saw many students graduate in positions 7 and 8. However, he notes that growth is not inevitable. In engineering it is likely that many students leave in positions 3 and 4. The three alternatives to growth are *temporizing, retreat*, and *escape*. These names incorporate Perry's hypothesis that movement from position 1 toward position 9 is growth and thus is desirable.

Temporizing. Growth does not occur linearly. Instead, periods of intense growth are commonly followed by pauses or plateaus. Perry defined *temporizing* as a pause in growth over a full academic year. All students go through plateau periods. Temporizing is just a rather long plateau and by itself is not bad. It may be a period in which the student gathers strength for the growth that lies ahead. In this case the student often seems aware that he or she is waiting for the correct combination of energy and will to move on. In an alternate mood of temporizing the student waits for fate to decide what will happen and may drift into escape.

Retreat. Retreat is regression to earlier positions. The most dramatic such retreat is movement back to position 3 or 2 when the complexities of relativism and multiplicity become overwhelming. (Retreat into position 1 probably occurs, but in Perry's study these students presumably dropped out of Harvard.) Retreat into dualism requires an enemy. The student must be on her or his guard against the pluralistic university. Students seem to be most susceptible to retreating to dualism when they rely on authoritarian structures for emotional control. Retreat also occurs from higher levels but is not as dramatic. For example, a student may retreat from position 6 or 5 to position 4 where he or she can hide in the concept that "everyone has the right to his or her own opinion."

Escape. In escape the student avoids Commitment by exploiting the detachment afforded by positions 4 and 5. Perry's team noted two paths of escape both of which started from temporizing. In *dissociation* the student drifts into a passive delegation of responsibility to fate. She or he ends up in position 4. The alternate path is *encapsulation*, which may be a favorite of engineering students. In encapsulation one avoids relativism by sheer competence in one's field. The student becomes very good at engineering but avoids any questions of deeper meaning or value. Engineers can use encapsulation to stay in position 4 or 5 for years. Escape need not be permanent, and people find different ways to resume growth.

14.3.3. Perry's Model and Engineering Education

Although Perry's model and the later models that built on Perry's work have become quite influential in higher education in general, engineering education continues to lag behind. Perry's model was introduced in engineering education by Culver and his coworkers. Culver and Hackos (1982) presented an overview of Perry's scheme and discussed implications for engineering education. Fitch and Culver (1984), Pavelich and Fitch (1988), Pavelich and Moore (1996), Woods et al. (1997), and Marra et al. (2000) presented data on the positions in Perry's model of engineering students, and discussed educational activities to encourage student development. Culver (1985) considered values in engineering education and specifically related them to Perry's model. Hackos (1985) discussed using writing to improve problem-solving skills and to enhance intellectual development. The next year Culver (1986) continued his series by discussing how Perry's model was useful in explaining the effects of motivation exercises. Culver (1987) described applications of Perry's model in encouraging students to learn on their own. Unfortunately, engineering students' progress through Perry's positions is slow (Heywood, 2005; Pavelich and Fitch, 1988; Pavelich and Moore, 1996). Culver et al. (1990) discussed the redesign of design courses and curricula to aid the progress of students on Perry's model. Carberry et al. (2010) used the synthesis of models developed by Hofer and Pintrich (1997) to study the beliefs of first year engineering students. (Earlier efforts were made in engineering education to tackle some of the problems clearly posed by Perry, but Perry's scheme was not used.)

Perry's model has both value-free and value-laden implications for engineering education. Since the subject is less controversial, we will start with the implications that are relatively value-free. The major inescapable conclusion from Perry's model is that different students require different learning environments. This is no surprise since all models of learning come to the same conclusion. Students are not capable of understanding knowledge or questions that are too far above them as far as Perry's positions are concerned. If pushed to try to understand this material, they will become frustrated. How far above is too far? Perry does not address this issue. From our experience, questions that are one position above the student's position can, perhaps with considerable difficulty, be answered. Because these questions stretch the student, they are helpful for encouraging movement. Questions or knowledge two positions above the student's current position cause frustration. Students are capable of answering questions in positions below them although they may find these questions easy or may read too much into them. Appropriate teacher responses at each position were discussed with the descriptions of each position. How does the teacher provide an optimum learning environment for a heterogeneous class with students at a variety of levels? This is the key challenge of individualizing instruction, and there is no clear-cut answer. Some possible approaches were discussed in Chapters 5 through 10.

One result of professors learning about Perry's model is they become more tolerant of students' difficulties (Kloss, 1994). Engineering students are rarely stupid or lazy. They do not answer questions that are two or more positions above their current positions because they *cannot* understand either the question or the answer.

Most of the applications of Perry's model to engineering education involve the value judgment that growth on Perry's scale is desirable (at least up to some level) and should be fostered. Perry considered this question and decided that growth was both natural and desirable. However, his sample contained no engineering students and in many ways was quite narrow. Faculties need to face the question of whether or not to encourage growth on Perry's scale. Failure to encourage growth is equivalent to a negative answer. Currently, engineering students show little progress toward higher Perry levels and may actually regress slightly during their engineering studies, particularly during the sophomore and junior years when most courses are taught by lecture methods (Fitch and Culver, 1984; Heywood, 2005; Pavelich and Fitch, 1988). Thus, if the faculty decide that growth is desirable, engineering education must be changed—a conclusion reached by other studies for many different reasons.

As noted previously, there are clear moral grounds for strongly encouraging students in position 1 to grow into position 2. Students and practicing engineers in positions 1 and 2 will have significant difficulty practicing engineering in our multiplistic society. Fortunately, the samples reported by Fitch and Culver (1984), Pavelich and Fitch (1988), and Marra et al. (2000) showed very few students who were clearly in position 2 (and none in position 1). A large number of students were in transition between positions 2 and 3, and the mean position for all engineering students was about 2.8 in the earlier studies, 3.17 in the study by Marra et al. (2000), and ranged from 3.27 for first year students to 4.21 for seniors with one-third of the seniors in position 5 (Wise et al., 2004). Pavelich and Fitch (1988) found that the written test used to measure students' developmental levels (Measure of Intellectual Development, the MID) was quite conservative. Interviews showed students who were at levels 4 and 5. Students in transition between positions 2 and 3 can see and accept multiplicity in some areas, and they accept that authority does not have all the answers. This transition region appears to be the minimum region in which a student can successfully study engineering. These engineers cannot see the big picture, and without further growth they are unlikely to advance significantly in their careers. Fitch and Culver (1984) also reported many students in position 3 and a few in the transition between position 3 and 4.

The most impressive gains in engineering students in Perry's scale were those observed in the McMaster University Problem Solving program (Woods et al., 1997). Students increased from an average of 3.6 as juniors to an average of 4.7 as seniors. The McMaster program is integrated, intensive, extensive, and covers many topics such as listening skills in addition to problem solving. Pavelich and Moore (1996) using interviews observed gains from 3.27 as first year students to 4.28 as seniors at the Colorado School of Mines in a program with a considerable number of experiential courses. However, the bimodal distribution of seniors—a significant number of students were either transitioning into position 5 or in position 5, but a substantial although lower number of students were below position 4—was of concern. It appeared that a significant number of students had chosen an alternative to growth. Felder and Brent (2004a) review the results for engineering students.

The results for engineering students can be contrasted to Perry's sample of liberal arts students at Harvard where the average entering level was approximately position 4 and 75% were judged to be in position 7 or 8 at graduation. [Note: Perry had an unusual sample. Other studies have consistently found more students at lower levels (Kurfiss, 1988).]

The reasons for moving students to at least the transition between positions 2 and 3 are clear. Below this level they will have difficulty functioning as engineering students. Graduate students in thesis masters and PhD programs will have trouble functioning below level 3 since they will not be able to answer the question "What do they want?" Research in graduate school seems to be structured to encourage the transition to position 3 if the student is not already there. Continued graduate study often moves the graduate student into position 4. Thus, engineering schools have implicitly made the decisions that undergraduates should reach at least the 2-to-3 transition and that graduate students should reach level 3 or 4 before graduation.

Is this sufficient? Probably most faculty will answer no. They want graduate students to operate at least at the level of the better students (position 4), and they want undergraduates to approach this level (say the 3-to-4 transition). In this regard Perry (1970) offers an interesting quote: "Fifty years ago [1920], our researches suggest, a college senior might achieve a world view such as that of Position 3 or Position 4 on our scheme and count himself a mature man." However, the world has changed and current practice of engineering involves solving open-ended problems that are complicated by lack of data, interactions with various stakeholders, and rapidly changing conditions. To function as a seasoned engineer in this environment requires a person who is at level 5 or higher (Pavelich and Moore, 1996).

Superficially, it is easy to conclude that engineering education must change and take students past position 4. However, there are many cautions to consider.

1. Taking the student to position 5 will fill the student with doubts about engineering as a profession. If a school purposely takes a student to position 5, the school must ethically help her or him to at least position 6. Some of these students will decide to make a Commitment to another profession.
2. It is difficult to take engineering students to position 5 even if we decide we want to. Engineering education at the undergraduate level reinforces positions 2 and 3, and at the graduate level does little to push students to position 5. Engineering students are very adept at escaping into competence once they reach position 3 or 4.
3. Many employers are happy with the current graduates at both undergraduate and graduate levels. This includes engineering schools as employers of PhD's.
4. A consensus of engineering professors does not exist.
5. Absolute standards in physical laws are a useful mental construct despite the Heisenberg uncertainty principle. Perry's relativism can undermine this absolute standard (Graff et al., 1991.)
6. Many professors feel that there *should* be absolute standards in engineering ethics (Graff et al., 1991). This is a different value judgment than Perry's.

There are reasons for encouraging students to move beyond their current positions.

1. Growth appears to be natural and in this sense is "good."
2. Growth into positions 7 through 9 appears to be necessary to function well in important positions such as vice-president, dean, president, and CEO (e.g., see Florman, 1987, p. 178). In a technological society we need more engineers in these positions.
3. "The main trouble with engineers has not been their lack of morality. It has been their failure to recognize that life is complex" (Florman, 1976, p. 27).
4. For women, movement to higher-level positions is empowering and helps them overcome the stereotype that they are not the equals of men in engineering.

What types of activities and teaching encourage growth? Fitch and Culver (1984), Culver (1985), Culver and Fitch (1988), Felder and Brent (2004b), and Heywood (2005) make the following suggestions. First, since highly structured courses reinforce the lower levels, the curriculum should be restructured so that courses become progressively less structured. However, if the first year program is restructured to include design and ethics (see Section 9.1) the sophomore and junior years must also be restructured away from rote learning and application of formulas or students will backslide to lower levels on Perry's scale. Since lecture reinforces the students' belief that the professor is an Authority who has the answers, the amount of lecturing needs to be reduced (Moore, 1994). Second, a diversity of learning tasks is required, which means that the use of a single textbook in a course is probably not enough. Third, students need practical, concrete learning experiences such as case studies, simulations with commercial simulators, team projects, industrial experience, design-build-test-redesign, and so forth. These experiences should be designed to reinforce diversity. Fourth, a learning environment that supports risk-taking needs to be developed in engineering classes and in the university.

Additional suggestions can be added from the research of Belenky et al. (1986, 1997). First, the student needs assurance that she is capable, and this support is needed from the beginning. Successful programs for women in engineering always include a significant component of support. Unfortunately, many women distrust praise from male professors. Second, separating evaluation from instruction is valuable for many students. It is difficult for many professors to be supportive when they know they will have to evaluate later. Evaluation and instruction can be separated by using separate competency examinations scored by outsiders or by having separate help classes taught by instructors not involved in the graded class [aka *supplemental instruction*]. Third, professors need to think out loud instead of presenting prepackaged thoughts as finished solutions (see Chapter 5). Fourth, students (both female and male) who are following a feeling-oriented development path will probably apply a deep approach to learning for problems that are socially important. For example, instead of designing a gear for a race car, design a gear for an inexpensive replacement for bicycles. Even better, design both gears, and let students choose the one they want to work on. Finally, it is particularly important for professors of engineering and science "to avoid the appearance of omniscience" (Belenky et al., 1986, p. 216).

One learning environment designed to encourage intellectual growth is the *practice-theory-practice* model developed by Lee Knefelkamp, which has been applied in engineering education by Culver (1986, 1987a). In this model a concrete experience (practice) is used to introduce the concept. Then theory is developed to explain the experience. Finally, further practice is used to reinforce the theory and to provide an extension to other material. This type of cycle appears to be particularly important for women who find concepts useful in understanding their experience but balk at an abstract approach devoid of experience (Belenky et al., 1986, 1997). To be effective for producing intellectual development, the experiences and theory must be understandable at the stage of development of the student, but the experience must also challenge the student. Marra et al. (2000) found that first year engineering design courses had a positive influence on engineering students on Perry's scale with an increase of approximately 0.3 to 0.4. Learning cycles, which are similar and also encourage intellectual growth, are discussed in detail in Chapter 15. Service learning (Section 7.10) is also useful for encouraging growth, but the challenges can be too great for students at the lower levels.

Choi et al. (2012) developed a case study tailored to increase the Perry's level of sophomore engineering students by modeling it after cases successfully used to increase the Perry level of sophomore teacher education students. Unfortunately, the experiment with engineering students failed to show any change in Perry's level. The authors hypothesized that the reason for the different result was that four very short case studies were used with the education students while the engineers had a single long case study. The repeated lessons with short case studies may be much more effective in helping the students internalize that "multiple realities may exist simultaneously" (Choi et al., 2012, p. 10). However, the authors did not consider that changing engineering students may be more difficult than changing education students because the other courses taken by sophomore engineers tend to reinforce dualism, and engineering is probably self-selected by students who want definite answers.

Perry found that dormitory living helped move students out of the lower levels. He also found that liberal arts courses were very valuable in helping students grow. Can liberal arts courses help engineering students grow on Perry's scale? The answer appears to be of the "yes, but" variety. Florman (1987) is strongly in favor of liberal arts for engineers, yet he notes (p. 173), "One need not be a broadly educated scholar in order to be a topnotch engineer." Liberal arts courses can be useful, but they need to be courses with multiple possible answers. Beginning language courses and beginning economics courses have little effect. Engineers need to be mixed in with students from other areas to experience diversity. Since engineering students often see liberal arts courses as unimportant, engineering faculty and advisors have to work hard to change this opinion. And since the students do not take a critical mass of liberal arts courses, ideas of multiplicity and relativism need to be reinforced in engineering classes. The liberal arts courses should be selected to challenge the student successfully no matter what his or her level. Dissonance, which is necessary for change, can be generated by having students assume different viewpoints while engaged in writing, debates or discussion (Kloss, 1994). Students will often see that there are elements of truth in different viewpoints, which is a big step towards multiplicity. Thus, the courses must have significant writing, debates, or discussion.

Grondin and Roberts (2010) discuss the results from a small multidisciplinary engineering program that values the liberal arts. The seniors were requested to develop portfolios that demonstrated their development. The faculty judged most of the students to be in Perry's position 3. The development experiences the students used as evidence in their portfolios were:

1. Projects: 70%
2. Humanities and social sciences courses: 50%
3. Diversity on campus, history of engineering course, critical inquiry course: 30% each
4. Projects/papers in math or science, and work: 20% each

Although the sample was only ten students, it is clear that engineering students notice when a project they work on affects people.

One final implication of Perry's model is somewhat disturbing. Mature students may find beginning engineering and science courses intellectually unchallenging and perhaps even stultifying. These students may find liberal arts or the social sciences more intellectually fulfilling and drop engineering. Evidence for this is contained in the study of Tobias (1990) exploring why some students drop science and engineering. A paradoxical result is that with current course levels it may be advantageous to delay intellectual growth until students have completed the lower-level courses. Obviously, there are many views on how much engineering education should do to move students on Perry's scale, but there is absolutely no correct view.

14.4. CHAPTER COMMENTS

Piaget's theories have had a major impact on the teaching of science, but little impact in engineering. One possible reason is that engineers generally teach only engineers, whereas scientists teach everyone in the university. Thus, engineering classes have a small percentage of students who are in the concrete operational stage. Since there are few of them and most of them do not survive in engineering, it has been easy for engineering professors to ignore them.

Teaching Perry's model to graduate students can be an interesting experience. We have occasionally encountered strong resistance from strongly religious graduate students to Perry's value judgment that growth on his model is positive. The most palatable presentation of Perry's model for these students clearly separated the observed behavior (the positions) from the value judgment. In addition, these students preferred to consider relativism as a way in which people *can* look at the world instead of Perry's formulation that this *is* the way the world is.

There is a strong tendency to demand equal rights and opportunities for women without looking at the real differences between men and women that were discovered in the research by Belenky et al. (1986, 1997). In our opinion equal opportunity does not imply an education that is exactly the same for men and women. Since many current educational practices are more tuned to the ways men learn and develop, women have less opportunity to benefit. Ideally, an equal opportunity education would involve many educational opportunities that are helpful for students with very different developmental needs and methods of knowing. Belenky et al. (1986, 1997) noted that there are different methods of knowing than those identified by Perry (1970). Once we admit to more than one approach to knowledge, it is logical while studying multiplicity to expect multiple paths caused by different socialization procedures in different societies. What other paths might there be? Palmer (1983) discusses a spiritual path.

HOMEWORK

1. Students complain that Prof. Whatastar gives tests that are very different from the homework assignments; he also requires solving problems they have never seen before.
   a. Use Piaget's model and Perry's model to explain what is going on.
   b. What can the students do to prepare better for Prof. Whatastar's exams?
2. Explore the differences and similarities between a good sophomore engineering course and a good graduate-level engineering course according to Perry's model.
3. Students who earn B.A. degrees and then return to take engineering courses often do not do well. Although there may be a variety of reasons for this phenomenon, discuss possible reasons based on Piaget's and Perry's theories.
4. Discuss the pros and cons of sharing with students their level on Perry's scheme.
5. Individuals in the concrete operational stage often become very frustrated by science and engineering courses in college. Explain why. Should universities try to help concrete operational students grow into the formal operational stage?
6. Should engineering education be reorganized to produce larger gains on Perry's scale?
   a. Assume the answer is yes and argue in favor of changing the system.
   b. For part a, discuss what changes you would recommend.
   c. Assume the answer is no and argue against changing the system.

7. Classify yourself on Perry's model or on the modified model for women.
8. Do the third objective in Section 14.1.
9. Since "the use of a single textbook in a course is probably not enough" what other sources are you reading in addition to *Teaching Engineering*?

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CHAPTER 15

LEARNING THEORIES

When the first edition of *Teaching Engineering* was written, the use of learning theories in engineering education was rudimentary. At that time, constructivism, learning styles, and Kolb's theory were, for practical purposes, the only learning theories engineering educators were aware of. During the intervening twenty years engineering education has realized that student learning is the objective of the entire enterprise. This realization has made learning theories a very important part of engineering education and one of the five key research areas identified by the Engineering Education Research Colloquies (Special Report, 2006) and adopted by the *Journal of Engineering Education* as areas of interest. As a result of this interest in learning, we have increased the coverage in all of the sections of Chapter 15, and we have added Section 15.5 on *How People Learn,* which is a synthesis of learning theories.

15.1. SUMMARY AND OBJECTIVES

After reading this chapter, you should be able to:

- Explain how constructivism and the scientific learning cycle can be used to improve engineering education.
- List and discuss the dichotomous learning and teaching styles. Type yourself on these styles. Discuss what you could do to improve your learning and teaching.
- Compare and contrast the ILS and VARK learning styles.
- Delineate how learning styles affect learning and how they can be incorporated in engineering education.
- Explain Kolb's learning cycle and its implications for engineering education.
- Determine how you could employ Challenge Based Instruction in a specific engineering course.
- Explain Maslow's theory of needs and discuss applications in engineering education.

15.2. CONSTRUCTIVISM AND THE SCIENTIFIC LEARNING CYCLE

In Chapter 14 we discussed Piaget's dictum that individuals construct their own knowledge structures. By continually testing these knowledge structures against the external world and then adapting them to fit that world, most individuals acquire a knowledge structure that "works" reasonably well in their world. For most individuals a "working" structure or model must be socially acceptable. This is true even of scientific concepts. The resulting structure may not be "true" in any absolute sense. For example, many engineering students start freshmen physics with the belief that a constant force must be applied to keep an object moving at constant speed. This belief results from years of pushing wagons, riding bikes, and driving cars. For these purposes this "knowledge" is adequate. In first-year physics, Newton's laws are introduced, and the knowledge structure has to be reconstructed. Such a reconstruction may be difficult (see Section 15.2.1), but once developed it is adequate for most engineering and physics courses. In relativistic physics, students find that the Newtonian model is not adequate, and a new model must be incorporated into their knowledge structure. This more complicated knowledge structure includes Newtonian physics and driving a car as special cases.

15.2.1. Reconstruction of Knowledge Structures

What makes students go through the agony of reconstructing a knowledge structure? The answer appears to be the 1) disequilibrium caused by new data that cannot be explained by the old model, 2) motivation caused by the inability to solve required problems, and 3) the availability of a new model that explains the data. Many students find mathematical arguments and lectures with little discussion insufficient reason to discard the pre-Newtonian model (Bodner, 1986). Experiments with an almost frictionless system (such as a dry ice puck) are required to make students revise their model of the world. The inconsistencies between a student's model of the world and new data should be forcefully pointed out. Most students are motivated by grades and/or a desire for knowledge to want to be able to solve problems. The instructor then provides a plausible and understandable new concept or model, which can eliminate the disequilibrium by explaining the new data. The student will restructure or assimilate new data only if accommodation fails and he or she is motivated to reconcile anomalies and reduce inconsistencies.

This example illustrates several important points about the constructivist theory. Since the pre-Newtonian model has been reinforced by years of practice where it worked, this knowledge structure is securely lodged in the brain. Removing any entrenched knowledge structure will be difficult. Thus, an extended period of time focused on Newton's laws is required both in and out of class, which helps to explain why learning new material is often slow. Frequent and timely feedback on mistakes helps to strengthen the necessary but not sufficient disequilibrium. Since forming new knowledge structures is difficult, students must be motivated. Direct contact with faculty can have a very positive effect on reorganization of the knowledge structure, particularly for students who identify with authority figures. The reorganization is aided by presenting information in hierarchical form with explicitly stated rules for generating hierarchies (Kurfiss, 1988). Learning new material in a form easy to recall from memory is aided if students are given objectives that help them key on important material and if the material is presented in a well-organized fashion (Kiewra, 1987).

The usual lecture-homework sequence requires formal operations. Students still in the concrete operational stage have difficulty revising their knowledge structures. For those in this stage, the concrete operations of the laboratory can be instrumental in helping them accept the new organization of knowledge. The laboratory exercise has other advantages as well. The student must be active, unlike in a lecture where a passive approach is allowed and often encouraged. Reconstruction requires active mental effort by the student. The laboratory is also often a group activity, which encourages students to discuss their understanding of physics actively, and the experience provides support from the group. Finally, this example helps to explain why beginning physics is widely considered to be the most difficult first-year course (Tobias, 1990). Many students are overwhelmed by the need to use formal reasoning to revise well-entrenched commonsense knowledge structures quickly and totally in a large class which often appears unfriendly.

It is interesting to compare the constructivist view of learning with the traditional view of knowledge implicitly assumed by many professors. In the traditional view knowledge exists independent of the individual. The mind is a *tabula rasa*, a blank tablet, upon which a picture of reality can be painted. If the student is attentive, learning occurs when the teacher unloads his or her almost perfect picture of reality through well-designed and well-presented lectures. Most experienced professors can attest that this model does not work for most students. Unfortunately, the traditional model focuses on the delivery system and not on the learner. The minds of the learners are not blank tablets upon which the teacher can write at will. The constructivist theory says the tablets are not initially blank and only the individual can do the writing. The traditional delivery system, the non-interactive lecture, satisfies the conditions of the traditional theory, but not the conditions of constructivist theory. Fortunately, lectures can be modified so that the conditions necessary for learning are satisfied. These conditions are discussed in the remainder of this chapter, and specific modifications of the lecture method were given in Chapter 6. Following constructivist theory, the professor will become a facilitator of learning instead of a purveyor of knowledge. At times this facilitation is aided by lecturing, and at times it is not.

There are exercises and homework assignments professors can use to help students develop a knowledge structure. One useful assignment for every book chapter or section of the course is the development of a *key relations chart* (Mettes et al., 1981). A key relations chart lists and diagrams the key ideas, equations, relations, definitions, and so forth, on a single page. The instructor can first illustrate this procedure by handing out his or her own chart for a chapter; then students can be required to do the same for homework. The chart can be evaluated for accuracy, completeness, and conciseness. Finally, the assignment is no longer made, but students are urged to continue developing the charts. We have allowed students to consult their key relation charts (contained on a 3 inch by 5 inch card) during tests. Since the preparation of such a card is a useful exercise, this is an interesting alternative to open book tests. The presence of the card also helps to reduce student anxiety since they do not have to memorize.

A related exercise is to have small groups of students develop a *memory board* (Woods et al., 1975), which is similar to a key relations chart but is significantly more complete and is prepared as a group exercise. It can include more equations, rules, interrelationships, and problem-solving hints. Construction of a memory board is a group activity, which makes it useful for support and motivation, particularly for the extroverts in the class. Working in groups also provides social pressure for students to change constructs which appear to be incorrect.

A third related exercise is to have individual students or groups of students develop *concept maps* or *networks* (Smith et al., 1985). A concept map or network visually represents the relationship between concepts, usually two-dimensionally. Both the hierarchical relationships and the key cross-links between concepts are shown. Concept maps are complementary to key relations charts and memory boards since the concept map does not give equations, definitions, or ideas. It shows the relations between concepts without full explanation of the concept. Since it is a visual representation, a concept map is often fairly easy for visual learners to remember (see Section 15.3.2). Students need to be taught how to construct concept maps and then encouraged to develop them on their own. Smith et al. (1985) illustrate a scoring model for evaluating concept maps. Figure 5-1 is an example of a concept map. We suggest that students be allowed to choose which representation they prefer.

Problem solving appears to require both a general problem-solving strategy and specific knowledge (Kurfiss, 1988). For routine problems, the specific knowledge structure is probably sufficient since it includes a pattern for solving routine problems. When confronted with unusual problems, the solver finds that no pattern exists for solving them. General problem-solving heuristics help one start reconstructing the knowledge structure to solve the problem (Chapter 5). Without specific content knowledge the general procedures are insufficient. Thus, engineering professors need to teach both content and procedures. Perhaps surprisingly, showing novices worked examples helps them structure their knowledge and is an effective teaching procedure (Tuovinen and Sweller, 1999). Of course, the students then have to do solutions on their own.

The knowledge structure is usually reconstructed as described previously. Reconstruction is often a painful process that is not always successful. In some cases we think a faster and less painful alternative procedure could be employed. What if we used the students' knowledge structure and changed the way we taught the material so that the knowledge structure was mainly correct? If only small adjustments are needed to their knowledge structure, students would learn faster. The challenge is to find topics in engineering that students struggle with and determine if there is a way to adjust teaching the material to use the students' knowledge structures instead of fighting the knowledge structure. For example, can heat transfer be taught in a way that corresponds to students' ideas of hot and cold?

15.2.2. Scientific Learning Cycle

Piaget's ideas and constructivism have led to a theory of how to teach science, the *scientific learning cycle* (see Figure 15-1). (In the literature this is simply called the *learning cycle.* We have added the word "scientific" to differentiate it from Kolb's learning cycle.) This method was independently developed by Robert Karplus in physics and Chester Lawson in biology. [Anton Lawson, who developed Lawson's Test of Scientific Reasoning to test for Piagetian reasoning is the son of Chester Lawson. See Lawson et al. (1989) for a historical perspective and complete references.] It has been extensively used and tested in science education at a variety of school levels. There is considerable experimental evidence that the scientific learning cycle is more effective teaching science than more traditional methods.

In the exploration phase, students explore new phenomena with minimal guidance; for example, given a new mechanical linkage or a new circuit, their assignment can be to determine how it works. In this phase they discover for themselves some of the patterns and concepts involved. The exploration can be done individually or in groups.

In the second phase, called term introduction, invention, conceptual invention, or concept introduction, the professor introduces terms and definitions. Students are encouraged

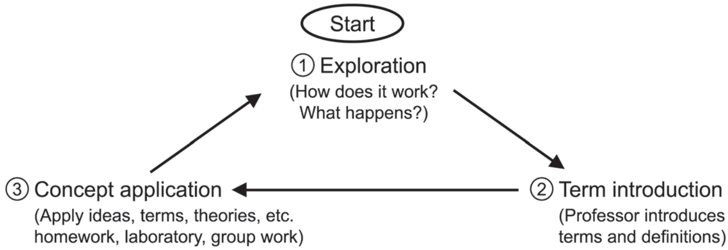

Figure 15-1. Scientific Learning Cycle

to use these new terms to describe the patterns as completely as possible. The professor then fills in the missing parts of the pattern to give a complete scientific picture. This phase can be accomplished through lecture, readings, video, guided discussion, and so forth.

In the third phase, concept application, concept expansion, or idea expansion, students apply the new ideas, terms, and patterns to new examples. For instance, if the exploration phase involves development of a new physical law, then the law can be applied in new ways. This phase can involve homework, group discussions, or laboratory.

Although developed originally for use with laboratory manipulations in the exploration phase, the scientific learning cycle can be modified for other types of experiences. For example, the exploration phase can involve a computer simulation that allows students to explore the simulated properties of some process or device. Alternatively, students can explore through video or even a lecture-question format. The key is to have students discover concepts on their own instead of being "spoon-fed."

The scientific learning cycle follows the ideas of constructivism. The exploration phase uses experiences (often concrete) to present data which cannot be explained by the students' existing knowledge structures. Students are encouraged to develop new knowledge structures by assimilation or accommodation, and the teacher ensures that this information is encoded with the correct terms. The concept application phase helps to organize the new knowledge structures.

The scientific learning cycle can easily be adapted to engineering education if appropriate laboratory equipment or computer simulations are available. Adoption of the learning cycle to lecture-style classes is more problematic but is certainly possible. Demonstrations in front of an entire class can represent a concrete chance to explore, although with less freedom than with individual laboratory equipment. Exploration can also take place in lectures if the instructor runs a simulation and then has the students predict what happens when a variable is changed. Let the students pick the new value of the variable. The instructor then runs the simulation and shows the results. In some cases running more simulations will be appropriate. The instructor has to be careful to allow students to discover concepts on their own. This approach may seem less efficient than the traditional lecture, but if efficiency is defined as student learning per amount of time, then the scientific learning cycle is more efficient.

15.3. LEARNING AND TEACHING STYLES

Individual preferences for learning and teaching are varied. Since mismatches can cause problems, professors should understand these styles. We have already explored learning styles in some depth, particularly in Chapters 13 and 14. These previous discussions on learning and teaching styles will not be repeated, but connections will be noted.

15.3.1. Dichotomous Styles

Many investigators have described dichotomies in learning styles. The Myers-Briggs scheme includes the *sensing-intuition* dichotomy, while Belenky et al. (1997) introduce the dichotomy between *separate and connected knowing* into Perry's scheme. In addition, both Piaget and Perry note the dichotomy between *rote memorization and true learning*. Other ways of looking at dichotomous learning styles are briefly discussed below.

Reflection versus impulsivity (Claxton and Murrell, 1987) measures the tendency either to reflect over possible answers or to impulsively select a solution. This appears to be a relatively stable trait, but individuals can be taught either to slow down or to speed up. Students who lean toward impulsivity need to be taught to slow down so that they at least read all the possible answers. Students who reflect for such a length of time that they either become immobilized or take an excessively long time on tests can become a bit more impulsive. When people live or work together for a long period, they tend to approach each other on this dichotomy (that is, some learning occurs).

The most important dichotomy is that between *deep versus surface* or *shallow* learning (Claxton and Murrell, 1987; Felder and Brent, 2005; Heywood, 2005; Marton and Säljö, 1997). Deep learners seek to learn the meaning and connections of ideas. For example, a deep learner seeks to learn the meaning of an equation and how to use the equation if the symbols are changed. The goals of deep learners are understanding and determining meaning. The goal of surface learners is to reproduce the information. They do not focus on understanding or determining meaning but instead on superficial form. Shallow learners tend to learn in terms of symbols and by memorization. If the meaning of symbols is changed, shallow learners have considerable difficulty in using an equation. Students in the concrete operational stage of development or the dualistic levels of Perry's model may not be able to do deep learning. Since deep learning skills appear fairly late in the developmental process, some college students who are capable of deep learning will not have developed the ability when they are first required to use deep learning. To encourage them to take the effort to learn to deep learn show the practical importance of the material (Felder and Brent, 2004).

Although they have a preferred learning approach, most engineering students are capable of both deep and shallow learning. The professor, through homework and tests, exerts considerable control over which type they use. If the homework and tests emphasize rote learning, then shallow learning is reinforced. A concern is whether assessments of ABET outcomes push students towards shallow learning (Heywood, 2005). This is probably a good reason for not requiring the memorization of a large number of equations. Examinations that can be answered with shallow learning, such as straight plug-and-chug exams, encourage shallow learning. Exams that do not have sufficient time also encourage shallow learning because thinking through a problem requires more time than shallow learning.

In the US, students are accustomed to science and mathematics courses where if they find the correct equation, plug in numbers, and calculate, they are pretty much guaranteed partial credit whether they understand the problem or not. With a little more sophistication the students will check that the units work, plug in numbers, calculate, and expect even more partial credit. This shallow learning is often sufficient in many engineering courses. However, two beginning engineering courses that stand out as requiring deep learning are mass and energy balances and circuits. In these courses students learn balance principles (balance mass and energy or balance electrons). Using the balance principle, students are expected to derive and then solve the equations for any configuration. As long as the professor does not teach the course as a series of algorithms by generating solutions for a large number of geometries, students must use deep learning to solve the problems. [Incidentally, students will rate this professor highly even though they do not learn how to deep learn. This example reinforces that students are not qualified to judge the appropriateness of the material they are studying (see Section 16.5).] Students who prefer deep learning usually do not find these courses tremendously difficult. Those who prefer shallow learning find the courses very difficult until they learn to deep learn. And those who do not learn to deep learn find the courses to be impossible.

Marton and Säljö (1997) identified *strategic learners* as a third style in addition to deep versus surface learners. Strategic learners decide whether to use deep or surface learning based on what will get them high grades. One can lament their crass focus on grades, but they have adopted an engineering approach of determining what is needed and then delivering it.

Even for students who prefer deep learning, *threshold concepts* are troublesome parts of disciplinary knowledge that are transformative for students since they open up new ways to think about an aspect of the discipline (Knight et al., 2014; Meyer and Land, 2003, 2005; Male et al., 2012a,b). These threshold concepts are often necessary for future learning and problem solving in the discipline. Threshold concepts can be a key concept that students must master to move forward with deep learning. Students who do not master the threshold concept will use surface learning and memorization to try to survive. Knight et al. (2014) identified "critical flow" in open channel hydraulics as a threshold concept. We identified "recycle" as a potential threshold concept in mass and energy balances. On a somewhat broader level the principle of conservation has been identified as a threshold concept (Male et al., 2012b). On a still broader level "teamwork" has been considered transformative because it is used broadly in engineering practice and particularly troublesome because communication and interpersonal skills are required (Male et al., 2012b). Certain identification of threshold concepts is difficult (Knight et al., 2014) and requires extensive triangulation. As in most areas of education, there is controversy over threshold concepts. Rowbottom (2007) believes that they cannot be determined empirically because they are not sharply defined. However, in practice, experienced teachers can identify concepts in courses that are difficult for most students but must be understood for deep understanding. Spending extra time and developing a variety of methods to help students learn these concepts will increase student learning in the course.

Another learning style dichotomy involves *deductive versus inductive* reasoning (Felder and Silverman, 1988; Felder and Brent, 2005). Deductive reasoning starts with general principles and then deduces consequences from these general principles. For example, a variety of specific equations can be deduced from very general equations such as Maxwell's equations or the Navier-Stokes equations. Inductive reasoning starts with specifics and then proceeds to induce generalities. Inductive reasoning may appear to be a slower way to present new material, but it is the natural learning style. The inductive reasoning process is the natural way to construct a knowledge structure in a new area and is the style used in the scientific learning cycle. Inductive reasoning can be used by individuals at any level of development, whereas deductive reasoning requires that the individual be in the formal operational stage. Introductory textbooks and lectures are much easier for students to understand if they are written in an inductive style, starting with fairly specific simple cases and building to generalities (Felder and Prince, 2007). When students are seeing the material for the second time, deductive reasoning can be a very efficient presentation style. Since a preliminary knowledge structure exists, the students have something on which to build their deductions. Unfortunately, professors, who already have a knowledge structure, tend to select textbooks and develop lectures that are deductive because that style works for them. They forget or never realized that neophytes need an inductive style. At Arizona State University Anderson (1991) found that engineering students preferred an inductive style, while professors preferred to teach deductively. Clearly, there is a mismatch.

Field-independent versus field-sensitive represents another useful dichotomy for understanding the dynamics of teaching and learning (Claxton and Murrell, 1987; Heywood, 2005). Field-independent individuals are less cognizant of the surroundings or field when they are working on a given task. For instance, these individuals can study effectively in a crowded, noisy college union. Field-independent individuals are more likely to be autonomous, tend to dislike group work, and often self-select into analytical fields such as engineering, mathematics, and science. But since most companies want team players, the field-independent individuals can be at a disadvantage after graduation. Field-sensitive individuals tend to be more people-oriented and are often good at working with others because they are aware of subtle messages. They are strongly influenced by authority figures and peer groups. Achievement in a course does not appear to correlate with this dichotomy, but attitude and survival in a curriculum probably do. Groups which are underrepresented in engineering—women and underrepresented minorities—have a large percentage of field-sensitive individuals. Teaching methods such as collaborative learning, which are attractive to field-sensitive individuals, will probably help retain them in engineering (see Chapter 7). There is probably a strong correlation of field-independence with the MBTI introverted and thinking categories, and field-dependence is related to extroverted and feeling types.

People appear to process information either *sequentially* (serially) or *globally* (holistically) (Claxton and Murrell, 1987; Felder and Silverman, 1988). Serialists take information in logical sequence and build their knowledge structures step by step. They can function quite well without seeing the big picture and they learn best in well-defined, logical classrooms. Since most elementary and high school classrooms follow a sequential procedure, serialists often do quite well in school. Holistic learners are driven early in the process to create a knowledge structure that shows the big picture even though most of the details are missing. As they learn, holistic learners fill in the details. Serialists tend to be better at details, and holists are better at overviews or seeing how everything fits together. Obviously, skill at both tasks is useful. Advance organizers are extremely useful for holists and are probably ignored by most serialists. Since globalists often struggle, particularly in introductory courses, it is important for professors to provide some aid and encouragement. In advanced classes globalists may have an advantage since they can see connections and do syntheses which are difficult for serialists. At Arizona State University sequential learning was the preferred learning mode for engineering students and the preferred teaching style of professors (Anderson, 1991).

The final dichotomy involves *active* and *reflective* processing of information (Kolb, 1984; Stice, 1987; Claxton and Murrell, 1987; Felder and Silverman, 1988). This dichotomy is part of the Kolb learning cycle (Section 15.4). Active experimenters want to do something with the information in the external world. They want to discuss, teach, solve, or make something. They want to try the activity and learn by doing. This dimension is closely related to extroversion. Reflective individuals want to process the information internally (introversion). They want to ponder it. However, a non-interactive lecture is optimum for neither style of learner. As in the case of all the dichotomies discussed, individuals can learn to learn better if they can use both techniques when appropriate. Anderson (1991) found that engineering students prefer active processing, while the preferred teaching style is reflective.

The dichotomies do not appear to be independent constructs (Claxton and Murrell, 1987). Although not independent, each dichotomy adds to the picture of how people learn. However, people are complex and have the disturbing habit of not fitting into any theory.

15.3.2. Auditory, Kinesthetic, and Visual Modes

We use three different modes for perceiving the world: *auditory*, *kinesthetic*, and *visual*. Everyone without a major physical handicap has the ability to use all three modes. For example, at a feast you can first enjoy the sight (visual) of the food and the table. Then you can actually eat and enjoy the smell, taste, and feel (all kinesthetic) of the food and drink. Finally, after the meal you can sit back and enjoy the feast again by talking (auditory) about how wonderful it was. As in other aspects of learning, most of us have developed a favorite mode of perception for learning about the world. This favorite mode affects how we learn in different situations (Felder and Silverman, 1988; Felder and Brent, 2005; Murr, 1988).

Kinesthetic learning includes taste, touch, smell, feelings, and actually doing what one wants to learn. Kinesthetic learning is important for chefs, athletes, therapists, artists, skilled craftspeople, and others. Kinesthetic learning occurs in engineering education when students work in laboratories and handle real components such as circuit boards, valves, and machine tools. Passing objects around during a lecture not only spices up the class but also incorporates kinesthetic learning. Touch (haptics) can be useful to understand the smoothness of objects or the heat generated when a bearing is binding. The sense of smell can be used as part of the learning process for food process engineers, chemical engineers, and environmental engineers. Feelings or affective aspects of learning are always present. Success and praise can help engender a positive attitude (feelings) toward the course, while failure and criticism do the reverse. Although criticism is often necessary, professors should never try to humiliate or belittle students. Writing about something is a good way to learn, partly because it involves both kinesthetic and auditory learning.

Kinesthetic learning includes actually doing things. Defined this way, kinesthetic learning is the favorite learning method of most people. However, this definition then includes the sensory input sources (e.g., taste, touch, smell) with the active half of the active-reflective dichotomy. Felder and Silverman (1988) chose to include the active-reflective dichotomy and ignore taste, touch and smell because they are not particularly important in engineering education. On the other hand, Fleming and Mills (1992) and Fleming (1995) kept the action of doing as part of kinesthetic learning. Because of these differences, the learning styles models of Felder and Solomon (1991) (Section 15.3.3) and of Fleming (2011) (Section 15.3.4) look different, but the difference is to a large extent semantic.

Visual learners prefer to process information in pictures, and they prefer to learn from pictures, charts, diagrams, figures, actual equipment, photographs, graphic images, and so forth. If active learning is placed in the action-reflection dichotomy, visual learning appears to be the preferred mode of learning for most people (Felder and Brent, 2005) and was the preferred mode for engineering students (Anderson, 1991; Felder and Brent, 2005). The phrase, "A picture is worth a thousand words," is a common-sense way of saying that most people prefer visual information. For visual learners visual information is easier to understand and place into memory than words (Kiewra, 1987). Visual learning can be incorporated into engineering education in a variety of ways. Plotting equations to show their shape makes them much more real for many students. This can be done conveniently with calculators with plotting screens. Graphical solution methods are easier for many students to understand than solving equations analytically. Showing that the intersection of two curves is the simultaneous solution of two equations helps students understand what this means. Graphical solutions to more complex problems, such as a McCabe-Thiele diagram in distillation or a Bode plot in process control, help many students understand the solution procedure. Showing graphical integration procedures and comparing these to Simpson's rule or other integration procedures helps clarify for the student the meaning of the integration procedure. Correlations of data should be shown both in a figure with the scatter of data and as an equation with the correlation coefficient. Equipment sketches and diagrams should be insisted on for the solution of all problems. Computer-aided three-dimensional diagrams can help to clarify complex concepts in mechanics and other areas. Field trips or at least professionally produced videos of plant sites help students see the "real thing." For many students this one-time exposure to real equipment makes an entire semester of equations and problem solving much more understandable. Students in co-op programs and industrial internships also benefit from this aspect of visual education.

Auditory teaching methods, lectures and print, are most commonly used in Western education systems. Reading in Western cultures is a visual representation of auditory processing techniques. In contrast, Chinese ideograms are closer to visual processing, and Eastern education has a more visual character (Murr, 1988). Writing words or equations on the board is a visual representation of an auditory method. Few people prefer to use auditory learning if given a choice; however, choice is not normally part of Western educational systems. Successful students adjust to auditory teaching styles before they reach college. One of the basic tenets of learning theory is that learning is more thorough and is retained better if multiple modes are used to input and process information. Thus, auditory styles of teaching should be heavily supplemented with active learning and visual learning opportunities. Students need to speak, write, sketch, and solve problems. Since active and visual learning are the preferred styles for most students, as much of the course as possible should be presented in an active visual style.

15.3.3. Felder-Silverman Learning Styles Model and Index of Learning Styles

In the most cited article in the *Journal of Engineering Education*, Richard Felder and Linda Silverman (1988) developed a model of student learning styles based on their preferences between the two alternative learning methods in four dichotomies. The dichotomies included were active versus reflective, sensing versus intuitive (same scale as in the Myers-Briggs Type indicator, chapter 13), visual versus verbal (kinesthetic was excluded), and sequential versus global. In 1991 Felder and Barbara Solomon developed a psychometric tool, the Index of Learning Styles (ILS), to determine a person's preferences in the Felder and Silverman model. Litzinger et al. (2007) proved that the ILS is reliable and valid. The ILS is available free on the internet (Felder and Solomon, 1991), and because it is also useful the ILS has been widely employed in higher education.

Results from the ILS are available from a large number of students and faculty (Felder and Brent, 2005). The averages for engineering students and engineering faculty are shown in Table 15-1. Active students paired with a reflective professor form a mismatch. If we pair a large number of engineering students with a large number of engineering professors the fraction of time this mismatch will occur is $0.64 \times 0.55 = 0.352$. The mismatch between reflective students paired with an active professor will occur on average $0.36 \times 0.45 = 0.162$ fraction of the time. The total fraction of pairs resulting in mismatches is $0.352 + 0.162 = 0.514$. Since students are passive in a straight lecture with no active learning breaks or reflective pauses, all students are mismatched with straight lectures. In addition, since few students prefer verbal learning, they are also mismatched since lectures are verbal. Thus, it is not surprising that many students struggle to learn when professors lecture.

Fortunately, for a professor who pays attention to learning/teaching styles it is not difficult to develop teaching methods that better match students' learning styles. For example, use of active learning breaks and reflective pauses (see Chapter 6) in a lecture will make it easier for all students to learn. Sensing individuals often find lectures presented in an intuitive fashion to be hard to follow, so it is probably best to present the lecture in a sensing fashion. As long as they pay attention, a sensing presentation is not detrimental to intuitives. Lectures will inherently have a verbal component, but they can be made to fit visual learners by purposely including graphs, figures, photographs, demonstrations, and artifacts. If an overview of the lecture is written on the board and the first minute or two used to explain how the topic fits into the big picture, but the main flow of the lecture is sequential, both sequential and global learners can be accommodated.

Textbooks can, but often do not, accommodate both types of learners. Active learners will benefit from problems while reflective learners will benefit from questions that present para-

Table 15-1. Results of ILS for Engineering Students and Faculty (Student and Faculty Data From Felder and Brent, 2005)

Dichotomy	Students	Faculty	Student-Faculty	Student-Lecture*
Active vs. Reflective	64% 36%	45% 55%	Mismatch 51.4%	Mismatch 100%
Sensing vs. Intuitive	63% 37%	41% 59%	Mismatch 52.3%	Mismatch 52.3%
Visual vs. Verbal	82% 18%	94% 6%	Match 78.2%	Mismatch 82%
Sequential vs. Global	60% 40%	44% 56%	Mismatch 51.2%	Mismatch 51.2%

*Lecture is assumed to be straight lecture (verbal) with no active learning breaks and no visuals. The professor teaches using his or her favorite sensing or intuitive and sequential or global styles.

doxes or challenging comprehension problems. Detailed example solutions that use a standard problem solving strategy are particularly useful for sensing students. Frequent use of graphs, figures and photographs that are directly related to the instruction helps visual learners. Sequential students benefit greatly from a text that is laid out sequentially. A short overview of the chapter including learning objectives and occasional advance organizers help global learners.

Over the last twenty years we have administered the ILS to over 3000 undergraduates and 200 graduate students. Perhaps 5 to 10% of the students do not find the results useful because either they do not believe that they fit or two or more of the scales show no differentiation. The remaining students can see how the knowledge of their preferred learning modes can help them study more efficiently. For example, if their textbook does not fit their preferred style they may be able to find a text that is a better fit for them. If the professor always uses words-words-words, students can develop their own visuals. In study groups a mix of learning styles is useful because there will often be at least one student who understands a section and can explain it to the others.

15.3.4. Visual, Auditory, Reading, and Kinesthetic (VARK) Learning Styles

The VARK learning styles are another way of looking at learning styles that some faculty and students have found to be useful. The learning styles and a short 16-item test to determine the VARK learning styles was developed by Fleming and Mills (1992) and Fleming (1995). The VARK categories are a bit different from the definitions used earlier for the ILS.

- Visual—pictures, movies, videos, diagrams, graphs, flowcharts, symbols
- Aural—lectures, discussions, music, explain, audio tapes, stories, jokes
- Reading—reading and writing, taking notes, making lists, texts, manuals, handouts
- Kinesthetic (tactile)—movement, experiments, hands-on activities, role play, do it.
- Multimodal context specific– use modes singly depending on situation
- Multimodal combination—use two or modes simultaneously

Multimodality was designed into the VARK to match our complex multimodal world.

Typical questions for the different styles are given by Cherry (2014). A "yes" answer would indicate leaning towards this style. A number of yes answers are needed for a strong indication. Note: The VARK inventory is a bit different as it asks you to choose among four possibilities.

Visual Learners. "Do you have to see information in order to remember it?"

Aural Learners. "Do you prefer to listen to class lectures rather than reading from the textbook?"

Reading and Writing Learners. "Do you take a lot of notes during class and while reading your books?"

Kinesthetic Learners. "Do you have to actually practice doing something in order to learn it?

The VARK website data (Fleming, 2011) shows 35.2% of the people who took the VARK have a single preference with reading as the most common (13.9%). Thus, multimodal preferences (64.8%) are much more common than single preferences. The breakdown of multimodal preferences is 14.4% bimodal, 12.2 % trimodal and 38.2% all four. The percentages of various populations who chose the different categories is shown in Table 15-2. Because multiple choices are available, all the options possible need to be included. For example, the percentage of the population that included visual learning is,

Table 15-2. Total Percentage Selecting Different VARK Categories (Fleming, 2011)

Population	V%	A%	R%	K%	n =
Total	20.8	24.4	27.6	27.2	101,773
Females	20.8	24.0	28.4	26.8	62,816
Males	20.9	25.1	26.2	27.8	37,689
Students	20.8	24.5	27.4	27.3	89,301
Teachers	21.3	23.1	28.5	27.0	6767
Engineering	22.3	24.4	25.4	27.9	3963
University	21.2	24.2	27.7	26.9	29,193

$$V\% = \frac{\#\ \text{options: [V single} + 0.5(\text{VA+VR+VK}) + 0.33(\text{VAR+VAK+VKR})+0.25\text{VARK]}}{\text{Total \# options selected}} \times 100$$

The 0.5, 0.333 and 0.25 coefficients are to avoid counting preferences multiple times.

It is interesting to compare the VARK learning styles to the Felder-Silverman Index of Learning Styles (ILS). The VARK adds the kinesthetic category, including actions. Felder and Silverman (1988) used the active-reflective learner scale instead. If the two learning style measurements are in agreement, people who are rated as active on the ILS will include kinesthetic as one of their modes on the VARK. The most useful difference in the VARK is probably breaking the verbal scale in the ILS into two modes: aural and reading (includes writing). However, the VARK has no equivalent of the ILS sensing-intuition and sequential-global scales. Similar to the ILS the VARK inventory is available free online (Fleming, 2013). The reproducibility of the VARK learning styles indicator is adequate and there was "some evidence of the validity of the VARK scores." (Leite et al., 2010, p. 338).

The VARK learning styles have been used a reasonable number of times in engineering education. Lee (2009) used the VARK to determine why students had difficulty in his course on kinematics. Narayanan (2010) designed instruction in each of the VARK styles and found the best results with visual and kinesthetic modes. A training program for faculty had higher approval ratings from participants after redesign with VARK styles (Kothaneth et al., 2012). Many students find the VARK learning styles and the advice on how to learn material (Fleming, 2011) to be useful.

15.4. KOLB'S LEARNING CYCLE AND LEARNING STYLES

15.4.1. Kolb's Learning Cycle

Kolb (1984, 1985) developed a two-dimensional circular or three-dimensional spiral model of how people learn (see also Abdulwahed and Nagy, 2009; Claxton and Murrell, 1987; Felder and Brent, 2005; Heywood, 2005; McCarthy, 1987; McCarthy and McCarthy, 2006; Nicoll-Sengt and Seider, 2010: Stice, 1987). Kolb's model starts by developing four different learning steps from two dichotomies considered to be orthogonal to each other. The first of these, active experimentation (AE) versus reflective observation (RO), was discussed in Section 15.3.1. This dichotomy refers to how individuals transform experience into knowledge. In the active experimentation step individuals actually do things, see results. In the reflective observation step individuals examine ideas from several angles and tend to delay action.

The second dimension in Kolb's theory is the dichotomy between abstract conceptualization (AC) and concrete experience (CE). This dimension distinguishes between how an individual grasps or takes in information. In the abstract conceptualization step individuals use logical analysis, abstract thinking, and systematic planning. In the concrete experience step individuals learn from specific experiences and personal involvement, particularly with people, and tend to be nonsystematic.

Kolb considers each of these four steps to be part of a complete learning cycle. McCarthy (1987) modified and extended Kolb's model to apply it to teaching. McCarthy and McCarthy (2006) modified the names of the learning styles (Section 15.4.2). Unfortunately, the modifications can cause confusion, although the new names may be easier to remember.

The complete learning cycle (Figure 15-2) requires all four steps; thus, a proficient learner is able to complete all steps in the cycle although he or she prefers certain modes of operation. The cycle can be entered at any of the four steps, but usually starts with the concrete experience method of grasping information. This information is then transformed or internalized by reflective observation (RO). For complete learning the individual should continue around the circle and use abstract conceptualization (AC) to perceive the information that has now been changed by reflection. Next, the learner processes the information actively and does something with it (AE). For complex information the circle is traversed several times in a spiral cycle. The spiral may extend through several courses and on into professional practice as the individual learns the material in more and more depth.

Kolb's learning cycle describes the steps required for complete learning. Unfortunately, courses often take shortcuts and employ only one or two steps in the cycle, which results in significantly less learning. Most college education is geared to abstract conceptualization, but retention (hence long-term learning) is enhanced by use of other steps in addition. Requiring more active involvement by students increases learning because additional steps in the learning cycle are used. Cooperative education, internships and service learning aid learning of most students because they involve the student in doing and in concrete experience.

Kolb's learning cycle is useful for conceptualizing how people learn and for developing courses and training programs (Claxton and Murrell, 1987; McCarthy, 1987; McCarthy and McCarthy, 2006; Svinicki and Dixon, 1987). Stice (1987) and Svinicki and Dixon (1987) first discussed applications in engineering education. A lecture (RO) can be followed by requiring students to think about the ideas (AC), do homework (AE), and observe demonstrations or do laboratory experiments (CE). Retention should be significantly better than in a course requiring only regurgitation of lecture (RO) and homework (AE). The effectiveness of the RO step can be increased by involving students in a conversation about the material (Kolb and Kolb, 2005; Kolb et al., 2002). The conversation helps students reflect from many viewpoints. Abdulwahed and Nagy (2009) developed a model for laboratory education based on Kolb's cycle. Student learning in a process control laboratory was significantly better in the labs following Kolb's cycle than in traditional labs.

McCarthy (1987) showed that Kolb's theory is similar to many other theories of learning. She extensively modified Kolb's theory and applied it to teaching a variety of topics at all levels. McCarthy's 4MAT system has been applied to engineering classes by Abdulwahed

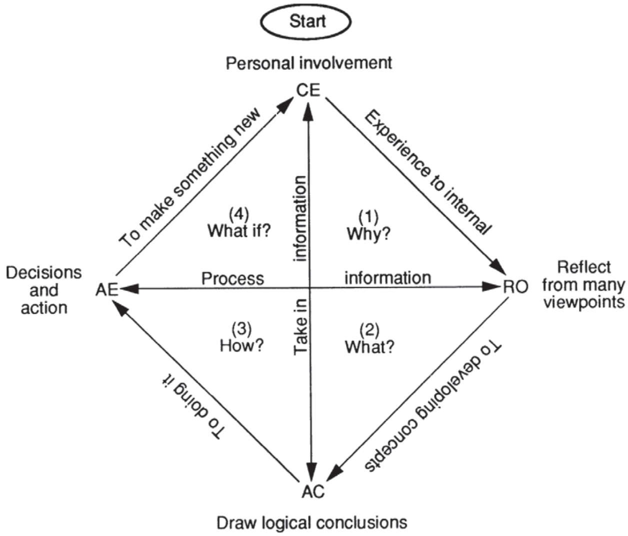

Figure 15-2. Modified Kolb's Learning Cycle and Learning Styles: quadrant 1, divergers (imaginative); quadrant 2, assimilators (analytic); quadrant 3, convergers (common sense); quadrant 4, accommodators (dynamic). Based on Kolb (1984), McCarthy (1987), McCarthy and McCarthy (2006), and Harb et al. (1991).

and Nagy (2009), Harb et al. (1991), Sharp et al. (1997) and others. McCarthy and McCarthy (2006) modified the 4MAT model and Nicoll-Senft and Seider (2010) discuss applications of the modified model.

The Kolb or 4MAT teaching and learning system starts each instructional unit with concrete experience (CE) and leads to reflective observation (RO). The student learns why the material is important in the first quadrant of Figure 15-2. This is the motivation step that professors often skip. McCarthy (1987) suggests performing first a right-brain-mode activity and second a left-brain-mode activity to create reasons for learning material. The right-brain-mode activity can be experimental, such as going out "on the street" and seeing and feeling the need for a bridge at a specific location. The purpose of this is to *connect* the need for the content knowledge to the student in a personal way (Nicoll-Senft and Seider, 2010) The left-brain-mode activity can then reflect on the need for the bridge. McCarthy (1987) suggests breaking down the learning activities in all four quadrants into both right and left brain activities.

In the second quadrant of Figure 15-2 students move from reflective observation (RO) to abstract conceptualization (AC). They think and learn concepts. The key question is "what?" What are the facts? What body of knowledge are the students supposed to learn? For students studying bridge building, various aspects of bridge design are covered in class. The teacher's role is to teach. This quadrant is normally the major part of typical engineering courses.

In the third quadrant students move from thinking to doing. They want to answer the question: How does it work? This is where homework assignments, laboratory sessions, and fieldwork fit into engineering education. In the example on bridge building, students can do homework on bridges and test model bridges in the lab. The professor coaches them and facilitates their efforts but lets them do it themselves. Engineering and technology programs include at least some courses where the third quadrant is heavily used.

In the fourth quadrant students remain active and move from active experimentation to concrete experience. This completes the cycle, but the students return to concrete experience with a different understanding of the knowledge. In the fourth quadrant they can teach themselves and others, ask "what-if" questions, and do something with the knowledge. They can create their own experiment or construct a model of their design. For example, for the class on bridges students can choose from a variety of projects such as designing a new bridge, building a model, producing a portfolio of bridge photographs, and so forth.

The usual college education uses a "pendulum style" of teaching: it oscillates between quadrants 2 and 3 but never goes around the entire cycle. Students are seldom motivated and seldom have the opportunity to go around the cycle themselves unless they have co-op or summer internships. The pendulum style reduces retention and does not satisfy the favorite learning style of many students.

15.4.2. Kolb's Learning Styles

Kolb also developed a theory of learning styles (Kolb, 1984, 1985; McCarthy, 1987; McCarthy and McCarthy, 2006; Svinicki and Dixon, 1987). A short psychological test that provides numerical scores is available (Kolb, 1985). The four styles are illustrated in Figure 15-2. Table 15-3 includes possible teaching and learning activities for each learning style. McCarthy and McCarthy (2006) changed the names of the learner types, but their characteristics were essentially unchanged. Since the new names are easier for most people to remember, we will use them.

Imaginative learners (*divergers*) prefer concrete experience and reflective observation (Quadrant 1). Often imaginative, emotional, and good at seeing the global picture, they tend to do well in working with people, recognizing problems, and generating many alternatives. Unfortunately, if too imaginative, they may not make decisions and not get things done. Imaginative learners often become artists, actors, personnel managers, counselors, and social workers. Imaginative learners do well in Quadrant 1 activities such as service learning and group exercises, particularly brainstorming-type activities.

Analytic learners (*assimilators*) prefer abstract conceptualization and reflective observation (Quadrant 2). They are excellent at understanding information and developing logical forms, prefer inductive reasoning, and are good at creating theoretical models. They can be contrasted with dynamic learners since they do not worry about practical aspects or people. They share the AC aspect with common sense learners but are often more interested in ideas than in people. Many teachers, writers, lawyers, mathematicians, scientists, and engineers with a scientific bent are analytic learners. Analytic learners often do well in lecture classes. Analytic learners are systematic planners, but they may ignore the human aspect and may have difficulty in practical, people-oriented activities such as internships and service learning.

Common sense learners (*convergers*) prefer abstract conceptualization (AC) and active experimentation (AE) (Quadrant 3) where they can do experiments and design equipment. They enjoy logic, practical application of ideas and theories to solve problems and are often quite focused. They tend to use deductive reasoning and are good at solving problems with a single answer. Most engineers are in the convergent learner quadrant (Svinicki and Dixon, 1987). If too convergent, they may tend to act without reflection and to think without feeling. As a result, they may be perceived as being arbitrary and cold. Since common sense learners need to relate theory to practical applications, case studies, laboratory, field trips, service learning, and work experience are very helpful parts of their education.

Dynamic learners (*accommodators*) prefer active experimentation and concrete experience (Quadrant 4). They are similar to common sense learners in that they like to act and to get things done. They differ from common sense learners in that they are less logical and are more people-oriented. If the theory does not fit the experiments, they will often discard the theory and go with what works. They enjoy new experiences and are often willing to take risks. Dynamic learners are often found in business or large organizations where they enjoy marketing, sales, managing, politics and public relations. They do well in hands-on group activities in class, group laboratory assignments, service learning, and internships. Dynamic learners may be seen as pushy and non-theoretical (a no-no in engineering education), and they rely heavily on trial-and-error. They often struggle in highly theoretical classes.

Note that these are *preferred* styles, but that everyone has the capability to use and the need to develop all four steps in the cycle. Working through Kolb's entire cycle automatically has students use all the steps. In addition, every student has an opportunity to shine when the learning activity is in her or his favorite quadrant. McCarthy (1987) found that higher percentages

Table 15-3. Teaching and Learning Activities for Different Learning Styles (Harb et al., 1991; McCarthy, 1987; McCarthy and McCarthy, 2006; Nicoll-Senft and Seider, 2010)

*Diverger (1) †Imaginative	Assimilator (2) Analytic	Converger (3) Common Sense	Accommodator (4) Dynamic
Motivation	Information and facts	Try it	Do it yourself
Reflective "War" stories	Reflective Lecture	Active Homework problems	Active Self-selected project
Brainstorming	Reading	Laboratory	Design
Observations:	Instructor or video demonstration	Simulations	Open-ended problems
Field trips		CAI	Write problems
"On street"	Patterns	Problem solving	Field trips
Logs	Organizing	Short answer	Work experience
Journals	Analyzing	Reports	Simulations
Role playing	Objective tests	Demonstrations	Teach yourself
Discussion	Library Work	Experiment	Teach others
Questioning	Examples	Tinker	Think tank
Visualization	Seminars	Record	Make things work

* Titles used by McCarthy (1987). † New titles used by McCarthy and McCarthy (2006).

of men than of women are analytic learners and common sense learners, which are the typical engineers, scientists, and technologists. Men generally tend to prefer abstract methods for taking in information, while women prefer more concrete approaches. Clearly, these style preferences are not cast in stone. Students who are in a program that heavily emphasizes a given learning style tend to shift their preferences toward that style (if they survive). A shift also occurs when graduates find that a different style is preferred in their jobs (Stickle et al., 1999). As people get older they tend to process information more reflectively and less actively.

Individuals who prefer any of the four learning styles can find a niche that will allow them to be successful engineers. After graduation, dynamic learners tend to move toward management, sales, and marketing; imaginative learners move toward personnel and creative positions. Common sense learners tend toward hard-core engineering jobs such as plant operations, design, and construction. Analytic learners gravitate toward research, development, and planning. Since technically trained people are needed in all these jobs, it is important to design educational programs to retain students with each of these styles. In school, common sense, analytic and imaginative learners are likely to find kindred spirits among both teachers and their peers. Thus, it is the dynamic learners who are most at risk in engineering education.

If the teacher's style differs from those of students, the mismatch can cause problems. Analytics emphasize logic, abstract theories, and ideas without applying them to practical problems. Dynamic learners in the class may not see the practical applications of the material and will consider the class to be impractical. All students may have problems applying the theoretical material to real situations. This mismatch often explains why engineering students are unable to use mathematics they studied earlier. The teacher can help all students by including all aspects of Kolb's learning cycle. This provides activities that are appropriate for each student, and helps each student broaden his or her repertoire of skills. A modification used by Sharp et al. (1997) is to design different writing assignments for each of the four Kolb learning styles.

15.5. HOW PEOPLE LEARN

Every once in a while a publication comes along that has tremendous impact on engineering education. *How People Learn* (HPL) (Bransford et al., 2000) is an example of this phenomenon. HPL did not break new ground except as a synthesis of other learning theories. Many of the ideas in HPL were adopted in the Carnegie Foundation's prescription for revitalizing engineering education (Sheppard, et al., 2009) and in Challenge Based Instruction (discussed later). The seven principles of learning chosen by Ambrose et al. (2010) overlap considerably with HPL.

One of the key principles in HPL is that "*people construct new knowledge and understanding based on what they already know and believe*" (HPL, p. 10). The corresponding statement from Ambrose et al. (2010, p. 4) is "*Students' prior knowledge can help or hinder learning.*" This principle is familiar from Section 14.2.3 on Piaget's theory of learning and 15.2 on constructivism. Since students are trying to learn, their preconceptions are very important. If their initial knowledge structure is close to correct, reconstruction is not needed and learning occurs. If the preconceptions are incorrect they will obstruct learning even if they remain hidden. Students will learn to calculate and do problems at the application and analysis levels of Bloom's taxonomy, but since they have bypassed the comprehension level they may have great difficulty with novel situations. Fighting preconceptions is difficult, but if students take an active role they are more likely to be successful. For example, recycle streams are probably the most difficult concept in mass balances because they are foreign to most students (Wankat, 2002a). The students usually have the incorrect preconception that the recycle cannot have a flow rate greater than the feed. If students are asked to take the role of molecules and are put into a process with a reactor and a separator that recycles unreacted molecules, through the role play they quickly see how the flow rate can increase and how it can be calculated. After the role play, a ten minute lecture on calculation procedures has more impact than an hour lecture without the role play.

A second principle of HPL is that students need to learn to control their own learning through *metacognition*—monitoring their own learning—by first making sense of it, then self-assessing their learning and finally reflecting on what they have learned. Ambrose et al. (2010, p. 6) state the same principle in different words, "To become self-directed learners, students must learn to monitor and adjust their approaches to learning." Consider the recycle example above. At first a student is confused, and she realizes she is confused. In the role play she plays the role of a molecule and sees how molecules become clustered together. A light bulb goes on and she understands—not totally, but enough to make sense of why recycle works. After the mini-lecture she works some problems, gets the correct answer, and realizes she is on the right track. She later reflects on the process and may become confused again because the ideas are not fixed in her knowledge structure. After a second opportunity to work on recycle, the ideas become more fixed. Her early *success* with a recycle problem after the role play was critical because success provides motivation which helps her over the rough patch of later confusion.

The HPL principles guide the instructor in preparing to teach. First, the instructor works to understand the students' preconceptions—if the instructor has taught the course before, the preconceptions may be obvious. Then the instructor develops a method for the students to become aware of their inaccurate preconceptions. Real data gathered by the students is most effective. In the recycle case personal experience from the role play was sufficient data.

Next, after the validity of the preconceptions has been undermined with the data, the instructor helps the students organize their ideas with a mini-lecture. Ambrose et al. (2010, p. 4) list their second principle, "How students organize knowledge influences how they learn and apply what they know." If possible, this lecture should first go from the data to a general principle (inductive reasoning), and then apply the general principle to other specific situations (deductive reasoning). Be sure to give at least one example. At this point *deliberate practice* in class in small groups is very effective in helping students learn complex tasks such as problem solving. What makes deliberate practice different than just solving problems is that students do a single step at a time (e.g., draw a sketch), receive feedback on that step, and have to revise as needed before moving to the next step. With deliberate practice students can learn complex skills much faster than without deliberate practice. However, students need repeated practice with feedback to learn any new skill. Ambrose et al. (2010, p. 5) list two practice-related principles: "To develop mastery, students must acquire component skills, practice integrating them, and know when to apply what they have learned." Goal-directed practice coupled with targeted feedback enhances the quality of students' learning.

Students need assignments to work through on their own time. The assignments are then collected, partially corrected, and returned to the students who use the corrections to develop a complete correct solution. Part of their assignment is to reflect on the problem solving. Since reflection does not come naturally to many engineering students, guide the reflection with questions such as, "What did you learn that will be helpful in solving other problems?" And "What were some of your misconceptions when you first tried to solve the problem?" Another assignment that can help students learn to reflect is to have them elaborate on and restructure their notes from a lecture. Since this is an assignment, students will spend focused time on task. Students who restructure and reflect on their notes had a significant increase in test scores (Cohen et al., 2014).

HPL borrowed the idea of the *zone of proximal development* (ZPD) from Vygotsky (1934). Vygotsky discovered that although children may have a very limited range of skills they can do without help by themselves, they can do a larger range (the ZPD) of skills if helped by a coach. In college the coach can be the instructor, the TA, or peers in a group or an ITS system (Section 8.6). As students succeed within the ZPD they broaden the range of skills they can do without help. The idea of scaffolding—providing support initially and then withdrawing it when appropriate—follows naturally from the ZPD (Hassan, 2011). Scaffolding often occurs naturally as students learn to solve problems. First, the student is able to understand the professor's example solution, and with help from a study group the student can solve similar problems. Then the student can do similar problems in a homework assignment without help. Next, the professor presents an example of transfer of knowledge and provides a chance to practice, with help if necessary. Finally, ideally before the test, the student can transfer the knowledge to solve different problems that use the same fundamentals without help. Without the example and chance to practice, requiring transfer on a test is a *big* step that many students consider unfair.

Bransford et al. (2000) determined that the ideal classroom environment should be:

1. Learner centered. Focus on preconceptions, skills, and motivation.
2. Knowledge centered. The goal is to have students understand and master the material. Learning-centered courses will have less cheating than performance-oriented courses (Section 12.2).
3. Assessment centered. The procedures discussed above had frequent formative assessment with rapid feedback and the opportunity to try again. Lang (2013) agrees with HPL and notes that frequent assessments can tap into the testing effect (Section 11.2.1). Some of these assessments should be immediately after the students have learned the material. In addition, Lang notes that some of the assessments should be for low stakes (e.g., have little effect on the students' grades). Not only will these measures increase learning, they also will decrease cheating (Section 12.2).
4. Community centered. Most students learn better in a community of learners. This is an idea from Vygotsky (1934), Bandura (1997) and others (Hassan, 2011; Alias et al., 2014). Thus, cooperative group learning (Section 7.4), PBL (Section 7.5), service learning (Section 7.10), and learning communities (Section 10.4.4) all fit within the HPL framework. However, HPL also preaches individualizing instruction, and some students are group-phobic. Forcing everyone to be heavily involved in groups all of the time will not result in the best learning environment for all students.

Principle 6 from Ambrose et al. (2010, p. 6) focuses on the interaction of the student with the environment, "Students' current level of development interacts with the social, emotional, and intellectual climate of the course to impact learning."

Complete application of the HPL process is time consuming, but because it is based on sound educational research it works. *Challenge Based Instruction* (CBI) is an inductive approach based on the HPL analysis that uses a six step learning cycle. CBI has been used to structure engineering courses, particularly in bioengineering where the method increases students' competencies in core areas (Hirsch et al., 2005: Roselli and Brophy, 2006; Cordray et al., 2009). The steps (Choutapalli et al., 2012; Cordray et al., 2009), which are similar to Kolb's cycle or the engineering design process, are designed to get students to see the need for further information before it is presented and to think through the problem before trying to solve it:

1. *The Challenge*. A question or task focusing learners on objectives.
2. *Generate Ideas*. Small groups develop and share ideas related to the challenge.
3. *Multiple Perspectives*. Discussion of ideas of all small groups. Expert views from books, internet, video and experts.
4. *Research and Revise*. Students apply what they have learned and continue to obtain new information to solve the challenge. Course instructor may give a short lecture *after* students realize need for information. Instructor assigns small problems to prepare students to attack the challenge.
5. *Test Your Mettle*. Formative assessments with rapid feedback. Depending on assessment results, may recycle to step 3.
6. *Go Public*. Summative assessments or public presentation.

The process can last several periods or weeks before the "Go Public" step when the solution to the challenge is presented. Often a major challenge is broken into a series of smaller challenges with the students completing a learning cycle for each small challenge.

Faculty often find switching from lectures to CBI or other inductive based learning approaches difficult (Crown et al., 2012). Workshops and mentoring assistance for both faculty and TAs are critical to success. The HPL methods are used to develop a survey that TAs can give to their students for feedback (Zhu et al., 2013). The result of the surveys can then be tabulated into an HPL-based teaching profile to help the TA translate theory into practice. To find the time to use the HPL methods you need to either control content tyranny (Section 6.3) or use a flipped classroom (Section 7.2).

A final comment: Heywood (2005) notes that Bransford et al. (2000) never mention learning styles. In teaching, there are multiple approaches to achieving student involvement that will result in student learning.

15.6. MOTIVATION

Regardless of their learning style and basic intelligence, students will not learn if not motivated. We cannot force them to learn, so motivation is crucial. "Students' motivation determines, directs, and sustains what they do to learn" (Ambrose et al., 2010, p. 5). Although much of this motivation is beyond the teacher's control, he or she can do a great deal either to motivate or demotivate students.

Motivation is usually considered either intrinsic or extrinsic. Intrinsic motivation is internal. It often satisfies basic human needs, which include physiological needs, as well as the need for safety, belongingness, love, esteem, and, finally, self-actualization (Maslow, 1970). Extrinsic motivation is externally controlled and includes many things that the instructor can do, including grading, providing encouragement and support, and so forth. The differences between intrinsic and extrinsic motivation are not always sharp. For example, a high salary might be considered to be an extrinsic motivator, but it can also enhance an individual's self-esteem. Both intrinsic and extrinsic motivation will be related to Maslow's theory of human needs and motivation.

15.6.1. Student Motivational Problems

Students can have a variety of motivational problems. Since the "cure" often depends upon the problem, it will be helpful to list some of the problems briefly.

1. The student does not want to study engineering or even to be in college. A surprising number of students are in engineering because of parental pressure. Failure is one way the student can prove that the parents are wrong. Research clearly shows that students who do not believe in the importance of education have lower success in school (*What Works*, 1986).
2. The student is not under pressure to be in engineering but is uncertain if engineering is the best choice. Since many outstanding engineers were once in this category, a major motivational effort may be appropriate. The motivation effort can focus on helping the students see how their studies open up interesting career opportunities. Once purpose is instilled, these students can become outstanding engineers.
3. The work ethic is absent. Many students who coasted through high school find engineering painfully hard work and may receive grades much lower than they are accustomed to. The shock of low grades is often sufficient to make the students realize that they have to study much harder. On the other hand, some students refuse to do as much work as engineering requires and leave engineering.
4. The background is inadequate. Success is very motivating, but with an inadequate background students may be unable to be successful. Remedial courses can help, but the graduation rate in engineering of students who start in remedial courses is low.
5. The student feels isolated and perhaps discriminated against. This can particularly be a problem for women and minorities who are traditionally underrepresented in engineering. It can also be a problem for international students.
6. The student finds engineering classes or classes in general distasteful. If the student's learning styles are very different from the professors' teaching styles, the student may find classes unrewarding even if they are not difficult. Some students find engineering classes too competitive or feel they never get rewarded for their efforts. We (professors) can be too critical.
7. External problems are overwhelming. Family crises, health problems, financial difficulties, relationship problems, and so forth can prevent students from focusing on their studies.
8. The student becomes overly anxious during tests or while doing homework. The discomfort caused by excessive anxiety reduces motivation. High stress on tests is detrimental to all students but hits women harder than it does men (Svinicki and McKeachie, 2014). Anxiety and stress can be controlled by desensitization procedures (such as giving more tests), by relaxation methods (see Section 2.8), and by using contract grading. Referral to a counseling center or to an office that will test for learning disabilities may be appropriate.
9. The student wants only a grade or a degree and does not care about learning the material. Although the professor may think that the student is motivated for the wrong reason, these motivations can be used to get the student to learn.
10. The student studies ineffectively. Provide strategic, concrete advise to the student how to study for your course (Ambrose et al., 2010). For example, collect comments on how they studied for your course from all students who received an A grade and distribute these comments to the class the next time you teach the course (Lang, 2013).

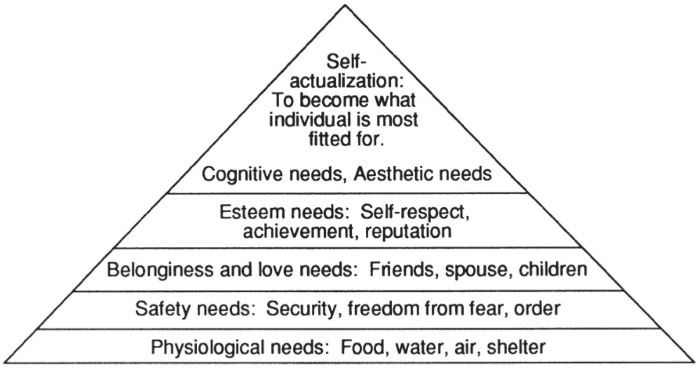

Figure 15-3. Maslow's Hierarchy of Needs

11. The student is not intelligent enough. We placed this reason last since, contrary to the opinion of many professors, the lack of intellectual ability is seldom the major reason for a lack of motivation, although it may contribute, particularly for concrete operational students. A significant body of research shows that "accomplishment in a particular activity is often more dependent upon hard work and self-discipline than on innate ability" (*What Works*, 1986).

15.6.2. Maslow's Hierarchy of Needs

According to Maslow (1970), individuals have a hierarchy of needs (Figure 15-3). When a need is unfulfilled, the individual is very motivated to fulfill that need. Once needs at the lower levels are satisfied, higher-level needs become important and the individual becomes motivated to satisfy these needs. If one of the lower-level needs is suddenly not satisfied, then this need becomes the most important need until it is again satisfied. For example, a PhD who is lost in the woods and starving thinks only about food and rescue, not abstract theory. Maslow noted that the hierarchy is not invariably followed by all individuals.

Western society tries to satisfy the physiological and safety needs for everyone, although not always successfully. Since professors and most students have these needs satisfied, many of us tend to ignore their importance. Professors need to remember that for some of their poorer students these needs may be very important. It is difficult to focus on studying if one is wondering where money for food or rent will come from. This type of external problem needs to be solved with financial aid, not by exhortations to study. A student who is terrified to walk back to a dorm after dark will not benefit from help sessions or the availability of a computer laboratory. These safety needs must be met by proper campus lighting, police patrols, and an escort service before the student can focus on studying.

When students leave home to go to college, they often find that the needs for belonging and love are no longer satisfied. Parents and friends several hundred miles away may be insufficient to satisfy these needs. Part of the adjustment process for freshmen, transfer students, and new graduate students involves satisfying the belongingness needs in a strange location. The adjustment process tends to be worse for freshmen because they have less experience in satisfying these needs on their own. The school can help by encouraging students (and for freshmen, their parents also) to visit before registration. Mixers and other get-togethers are useful in helping new students meet others. Living in a residence hall is particularly helpful to freshmen and also helps their development on Perry's scale (see Chapter 14).

Professors have an important role to play in helping to satisfy belongingness needs. Retention is significantly enhanced when students are integrated into the university both socially and academically (Smith, 1989, 2009). Academic integration includes contact with faculty and staff, involvement in courses, and academic performance. Students who make significant contact with a faculty member during the first six weeks of the semester are more likely to become academically integrated and remain at the university. At a minimum the professor must learn everyone's name—a challenge in large courses. A more active approach such as inviting small groups of students to his or her house or for coffee at the student lounge can have a positive impact. Significant contact almost always occurs for new engineering graduate students who are seen as a resource, but at large universities is often absent for freshmen. Students who do not want to be in engineering or who are unsure about engineering have more difficulty achieving academic integration. Counseling, support, and encouragement can help these students. The ability of engineering to satisfy other needs may help them become academically integrated. Thus, spending time in introductory classes talking about the positive aspects of being an engineer helps some students get past a difficult period. Unfortunately, the sting of negative feedback lasts much longer than the glow from positive feedback. Be creative in finding ways to use positive instead of negative feedback.

Students with very different learning styles often do not feel that they belong in engineering. A relatively small amount of course modification (Section 15.3) to include other learning styles can help these students feel they belong. A particularly important change for many students is to make learning more cooperative and less competitive (Smith, 1989, 2009). Cooperative group exercises and grading that does not pit students against each other can help convince them that the true adversary is ignorance, not the professor or each other. The need to belong can have a negative impact on the student's desire to study since some groups may exclude students who do too well in class. This can be combated by developing groups such as honor societies, study groups, or professional organizations where academic excellence is appreciated.

The need for esteem can often be fulfilled in class. Grades are often a powerful motivating device (Svinicki and McKeachie, 2014) because they directly relate to the esteem needs and are under the professor's control. Achievement, reputation, and self-respect can all be enhanced by good grades. Success is motivating (Bransford et al., 2000). Excusing students from the final because of good grades during the semester can be an excellent motivator for the better students. Yet grades won't motivate if students believe that high grades will interfere with their belonging, and the belongingness needs are unfulfilled. Good grades must also be seen to be achievable. Students with poor academic backgrounds and/or poor study habits quickly come to believe that they cannot achieve good grades. For them, grades demotivate. Remedial help, tutoring, and support from an advisor or professor can help these students succeed. Another valuable modification is to use a flexible time frame and allow the students to spend more time learning (see Section 7.7). Since every student can achieve if given sufficient time and encouragement, these classes can be very motivating.

Needs for esteem and belongingness are also met by respect from faculty. Eble (1988) states that respecting students as human beings without requiring them to prove themselves is one of the most important things a teacher can do to help them grow. Feedback should be immediate, and if at all possible should contain some positive aspects. Effort should be praised even if it is somewhat misplaced. Professors can learn from successful coaches in this respect. In basketball when a player fouls, the coach may praise the player for good hustle and then correct him or her for the foul. Negative feedback should be avoided if possible, but if necessary it should be focused entirely on the performance and not on the person. Unfortunately, negative reinforcement may result in unexpected and undesired behavior changes such as avoiding class entirely to avoid being criticized. Criticizing a student as lazy is an attack on the person. In the long run, it is usually more productive to point out that the performance is not up to the student's ability and is not satisfactory. Smiles, nods, and encouragement for responses are all positive reinforcement. Greeting a student by name with a smile in the hall or in your office is also positive reinforcement that can help to meet the student's esteem needs. This reinforcement is unexpected and intermittent and thus is very powerful. Many students who leave engineering cite discouragement and the lack of support as major reasons (Hewitt and Seymour, 1992).

Assignments and tests motivate students to keep up with the class since they tap into the need to be successful and avoid failure. Introduce assignments and tests with positive expectations for student performance. Motivation for doing tests and assignments appears to be highest when there is a fair but not certain chance for success (Svinicki and McKeachie, 2014). Try to ensure that there is some aspect of the course at which each student can be successful. The workload should be reasonable since excessive work is demotivating and reduces the chance of success.

The prospect of a good salary upon graduation is often considered a crass extrinsic motivator. Based on Maslow's theory, there are often good reasons why the promise of salary is a strong motivator. If the student experiences periods when physiological or safety needs are not met, then the salary can be a way of ensuring this does not happen again. Engineering should promote itself as a way up and out of poverty. Parental pressure to go into engineering may arise from the parents' desire to have their child earn a good salary. If satisfying parents helps meet love and belongingness needs, then the student may be strongly motivated. For many students salary helps to satisfy the need for esteem. Since salary after graduation is a long way off for a freshman or sophomore, a summer internship or a co-op job may be a better motivator.

The chance to present a paper at a meeting and to be a coauthor on a published paper can help meet a student's need for esteem and reputation. This can be a tremendous motivator for graduate students. Students work harder on research when they have a self-imposed deadline (paper presentation or the desire to graduate) than when pushed by the professor.

In the highest level of Maslow's hierarchy, self-actualization, individuals need to reach their potential and control their own destiny. The need to self-actualize is what causes people to write poetry at 2 a.m. when they have to report to a respectable, well-paying job at 8 a.m. Cooking gourmet meals when something simpler would suffice may represent the need to self-actualize. Creativity and the need to create can be considered part of the need to self-actualize. Maslow notes that for extremely creative individuals the need to create may be more important than the lower needs. Self-actualization occurs in mature individuals and based on Maslow's studies is uncommon. Self-actualized students are more likely to be encountered in graduate or continuing education classes. In class they appreciate the chance to do individual projects and delve into a topic of their choice at considerable depth. Bonus problems and other methods, which give them some control over what they do, are appreciated. In research they want to guide their own projects. The professor's job is to step back and serve as a resource person when asked.

Maslow notes that cognitive needs are present throughout the five stages. There is joy in learning and creating, which can be used to motivate. However, professors must remove barriers that prevent students from achieving the joy of learning. The professor's enthusiasm and joy in learning the subject can be contagious. Students enjoy classes more and learn more when the professor is somewhat entertaining (see Section 6.4).

Curiosity is most evident in young children and self-actualized individuals. Professors can use curiosity as a positive motivator in the classroom. For example, try asking questions without answering them. We have found that questions that ask the students to use their engineering knowledge to explain nature often pique their interest. Why does a car window frost over at night when the window on an adjacent building does not? What is wind chill? Or, have the student estimate how long it will take for a person to respond on a very long-distance telephone call. This use of curiosity, like all motivating techniques, will work for only a portion of the class.

At all levels of Maslow's hierarchy the locus of control is important. People who believe they have some control over their life are more strongly motivated. Graduate students, in particular, who are given significant control over their projects, often respond with extraordinary energy. Undergraduates can be provided with a modicum of control with grade contracts, a choice of projects, a choice of problems on a test, or a vote on the test date. However, do not force autonomy on students who are not ready (Iphofen, 1998). Limiting the number of choices can help students who are not ready for autonomy.

15.6.3. Interactions of Value, Expectancy and the Environment (Ambrose et al., 2010)

Although motivation is complex, a reasonable explanation that can provide a guide for motivating students is to analyze the effects and interactions of the student's perception of the task's value, the student's expectation of success, and the student's perception of how supportive the environment is.

In order to be motivated to do something people need to value achieving the goal. Ideally, students will believe that learning the material is valuable—that is they will have learning goals, *intrinsically value* learning the material, and are intrinsically motivated. Many faculty chose to become professors because they intrinsically valued learning in their disciplines.

Instructors can help students see the value of learning the material by illustrating applications of the knowledge that are important to the students. Show the students that learning the material will help them reach other goals. In this case the material has *instrumental value*. Many students value their engineering studies because they believe engineering will lead to an interesting, well-paying job. This would usually be considered extrinsic motivation. There are often other student goals that can be satisfied by learning the course material. For example, one year while teaching distillation I had two students who were obviously very interested in the material. Talking to these two students after class one day I discovered that they were interested in making a stronger home-brew brandy. Thus, they valued the material being taught in class because they believed learning it would help them achieve their other goal.

Students who value specific goals will not be motivated to pursue the goal if they are not able to identify actions that will help them achieve the goal. For example, I value being able to beat the stock market and make money, but I do not know what specific actions will do this—buy low and sell high is not specific enough! Thus, I do not have *positive outcome expectancy*. Instructors can help students have positive outcome expectancies by being very clear what needs to be done to earn specific grades.

Positive outcome expectancies are necessary, but not sufficient to be motivated. One must also believe that one is capable of doing the task, which is *efficacy*. For example, many high school and college football players know the actions that will lead to success at the next level, but most are not capable of performing at the level required. Instructors can help students believe they are capable by connecting the new tasks to tasks that the students have already mastered. Emphasize that the students' hard work led to success in the past and will lead to success in the future.

Students who do not see value and have low efficacy will *reject* the class. These are the no-shows and dropouts. Students who have high efficacy but do not see value in the material will *evade* doing work. If they see the environment as supportive they may want to avoid disappointing the professor or the department and will do the minimal work to pass.

Students who see value in the course but have low efficacy will be destroyed by a non-supportive, unfriendly environment. If the professor tells the class that one third of the class will fail, these students believe that failure is their fate. Believing that study is hopeless, they then fail the course. In a supportive, friendly environment—the professor is friendly and accessible, computer and experimental tools are available and in good working order, and the class is cooperative—these students have a chance to succeed, but they are *fragile* (Ambrose et al., 2010). Because they value the class and the environment is supportive, they want to succeed, but they are afraid they do not have the ability. The instructor can help by providing opportunities for early successes. Be clear about the quality of work expected and give the students both rubrics and examples of good work. Talk to students who are struggling, particularly first year and sophomores, about effective study habits.

Students who see high value in the course material, who have positive outcome expectancy and high efficacy will be motivated to successfully complete the course regardless of how they perceive the environment. If they consider the environment is supportive these students will be highly motivated and positive about the experience. They may well do considerably more than is required. If the environment is not supportive—the professor and TA are not available or tell the students they will not succeed (one third of this class will fail) and barriers are put in the way of success—these students will become *defiant* and decide to show the professor they will succeed despite the difficulties (Ambrose et al., 2010).

Observation and *interpretation* of the instructor's actions must occur before the student considers the value, expectancy and efficacy of a task (Pintrich, 1994; Wankat, 2002b). Unfortunately, it is very easy for students to not observe an action correctly (e.g., students are often unable to solve a problem because they missed reading a key sentence) and/or to misinterpret what instructors do. For example, an instructor may truly want to help students, but if he is grumpy the first week of classes because of illness, some students will perceive him as being unfriendly. In this situation the students misinterpret the reason for the grumpiness and chose to stay away from office hours. Other students who did not observe the grumpy behavior may try talking to the professor outside of class, find that he is friendly, and start coming to office hours. In this case, not observing can prevent demotivation, but usually not observing is detrimental.

Instructors can also not observe or misinterpret student actions. For example, the instructor may interpret a student's sleeping in class as a lack of interest when the real reason is exhaustion because she was up all night with a fussy baby. Based on this interpretation, the instructor may consciously or unconsciously make the environment less supportive, which may interact negatively with the student's motivation.

15.6.4. Other Motivational Methods

Writers on motivation in college teaching (e.g., Ambrose et al., 2010; Eble, 1988; Lang, 2013; and Svinicki and McKeachie, 2014) note that teachers need to be creative in developing motivational techniques. Lang (2013, p. 61) observed that outstanding teachers felt that the "most important task they set for themselves was determining how to inspire students to care deeply about what they were learning—to put aside the grade and engage with the material in ways that would create deep and substantial learning." With a creative effort the professor can often find just the right thing to do to motivate a particular student. For example, we have seen graduate students become very motivated when given the opportunity to present a paper at a meeting or to mentor students. The chance to coauthor a research paper has sparked some undergraduates. Having a piece of equipment actually constructed and used while on a co-op assignment has turned students on to engineering. Taking a mastery class and being able to succeed academically for the first time in college has been a tremendous motivator for some students. One student obtained the help he needed once a professor took the time to sit and talk with him about the potential career consequences of his inability to communicate. Informal parties at a professor's house have helped many students feel at home at the university and thus have satisfied their belongingness needs. Often it is the attention and not the actual action that increases the students' motivation.

Unfortunately, negative behavior lasts longer and demotivating students can be relatively easy. Avoid actions such as ignoring, blaming, or making fun of students. However, the reactions of people are difficult to predict. The above behavior may challenge some students and they may decide to prove that the instructor is wrong by becoming successful. Students can react very differently to the same instructor actions because they perceive and interpret the actions differently (Ambrose et al., 2010; Wankat, 2002b).

Focus on learning instead of grades because students with a learning orientation are more motivated than those who just want to earn a grade (performance orientation) (Bransford et al., 2000). Provide sufficient time on exams so that students who reason their way to a solution are not penalized. Many students will be motivated by working in a small group, although some students dislike group work. Many engineering students are studying engineering because they want to be able to do useful work; thus, make sure the students are aware how the material is used. Since they want to be useful, most students find co-op jobs or internships, tutoring and undergraduate research motivating. HPL recommends:

1. Give students choices and opportunities to be responsible for their education. One way that this can be done that allows each student to individualize their learning is through assessments that the students choose (Ambrose et al., 2010;

Lang, 2013). For example, provide a large number of possibilities for earning points and list in advance the number of points that students need to earn different grades. Make sure that no one method is worth sufficient points that students can do it and nothing else. Students will pick methods that play to their interests and strengths and thus will individualize their learning. Assessments in this form will also drastically reduce cheating because every student picks their assessments and since each students package of assessments is likely to be unique students are less likely to compete for grades, which can lead to cheating (Lang, 2013).

2. Develop a climate that is enthusiastic, skilled, and uses student-centered teaching to encourage intrinsic motivation to learn.
3. Provide chances for success by providing problems at increasing levels of difficulty, giving feedback while valuing learning efforts, and providing role models.

This section barely scratches the surface of the motivation literature. For example, Lombardi (2011) introduces six authors on motivation that will be unfamiliar to most engineering faculty: Daniel Amen, Jere Brophy, Joseph Ciaccio, Rick Lavoie, Daniel Pink, and Richard Zull.

15.7. CHAPTER COMMENTS

There is wide-spread belief that students will learn more if their learning style (e.g., Felder-Silverman, VARK, or Kolb) is matched by the teaching style. This belief is not supported by the few rigorous experiments that have been conducted (Pashler et al., 2008). In other words, students whose learning style is closely matched by the teaching method do not learn more than other students taught by the same method if that method does not match their learning style. However, there is no evidence that student learning is harmed by matching their learning style. Related materials in this chapter such as auditory, kinesthetic and visual modes; dichotomous styles; and the effectiveness of teaching around a cycle are not controversial. We have included learning styles because they are strongly entrenched in engineering education, and instructors who focus on learning styles will naturally pay attention to student learning.

This chapter is not a complete picture of how individuals learn because that complete picture is not yet known. However, enough is known and well documented by research that we have made firm recommendations about what is known to work. Many of the suggestions can be tried piecemeal with little effort. Of course, we have been unable to cover all the theories that can be used to understand learning and improve engineering education. In particular, the research on right- and left-brain functioning has only been touched on and the research on expert systems and cognitive load theory have not been included. To learn more read Bransford et al. (2000) for an integrated overview, Sweller et al. (1998) for cognitive load theory, and Edwards (2012) and McCarthy and McCarthy (2006) for right-left brain applications.

Our experience in teaching is that some students become extremely excited about Kolb's theory. They read his and McCarthy's books, do a project using his theory, and plan on incorporating his theory into their classes.

We have caught flak from some students over the labels "field-independent" and "field-sensitive." Labeling the former as field-insensitive, which is just as accurate, may help students see that you are not degrading characteristics that are often labeled as feminine.

HOMEWORK

1. Develop a key relations chart for this chapter.
2. Develop a concept map for this chapter.
3. Pick a topic in one of your engineering classes.
    a. Determine how to teach it using the scientific learning cycle.
    b. Determine how to teach it using Kolb's learning cycle.
    c. Compare parts a and b.
4. Do the second objective in Section 15.1 (list dichotomous learning/teaching styles).
5. Do the fourth objective in Section 15.1 for a specific engineering class.
6. Choose a student whom you know well and who is not strongly motivated. Analyze this student by Maslow's theory. Determine some interventions which might help motivate this individual. Try one or two of the interventions.

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CHAPTER 16

EVALUATION OF TEACHING

It is natural to want to know how well one has done on a given task. In its simplest form, evaluation of teaching allows an instructor to obtain this feedback. Once collected, the data can be used to help the instructor improve the course, compare instructors, reward or punish the instructor, or inform potential students. Since improvement of teaching without this feedback is unlikely, we are in favor of this use of formative teaching evaluations.

During the 1970s and 1980s, there was considerable focus on use of student evaluations of teaching. The promise of student evaluations was oversold and in the rush to implement student evaluations there was misuse. These problems led to a large number of papers on student evaluation of teaching in the engineering education literature—most negative. The energy to study and comment on evaluations of teaching has apparently dissipated. The number of papers we found in engineering education journals during the last twenty years was considerably less than what we found prior to 1993. In their extensive literature review Johnson et al. (2013) cited 82 references, but only one from the engineering education literature. Perhaps when student evaluations of teaching were first required, engineering faculty went through the first five stages of grief:

1. *Shock*. I can't believe it. The students are going to rate us.
2. *Denial*. This can't be true. The students don't know how to rate teachers.
3. *Emotions*. #!%&. Give us a break.
4. *Resistance and/or Withdrawal*. This is really dumb. My promotion and raise is going to depend on the students. I won't do it.
5. *Surrender and Acceptance*. I guess student evaluations are not going away. At least the university finally developed a decent evaluation form.

In stage 5 people are quietly unhappy. Unlike students in active learning (see Section 7.12), the faculty apparently got stuck at stage 5, and never made it to stage 8, integration and success. Whatever the reason, research on teaching evaluation in engineering has essentially ceased for now. Most schools use student evaluations of teaching—fortunately, as we will show they can be made both reliable and valid for items that students can judge. Students cannot judge issues related to content (Hoyt and Pallett, 1999). Unfortunately, most schools do not use other means to evaluate the content of the course. Also, very few schools use any method other than student evaluations and student exit interviews (Section 16.5) to evaluate teaching.

We start with a discussion of formative and summative evaluations and the objectives of each; then we consider the validity of student evaluations, correlations with other methods, and extraneous variables that affect student evaluations. Since student evaluations are only one of many procedures used for evaluating teaching, we next discuss the various other methods.

Many professors in psychology and education have devoted their careers to studying the evaluation of teaching. Although many questions remain, there is a large body of scientifically valid knowledge about the subject. We tap into this knowledge so that the reader can intelligently discuss the issues surrounding the evaluation of teaching.

16.1. SUMMARY AND OBJECTIVES

After reading this chapter, you should be able to:

- Discuss the advantages and disadvantages of formative and summative evaluations.
- Explain the uses of teacher evaluations and discuss the controversies surrounding them.
- Discuss the various types of student ratings and how they should be administered.
- Compare the reliability of student ratings to the reliability of other evaluation methods.
- Discuss the validity of student ratings.
- Explain how extraneous variables can affect student ratings.
- Determine the types of courses in which you are most likely to do good or poor teaching.
- Discuss other evaluation procedures that complement student ratings.

16.2. FORMATIVE AND SUMMATIVE EVALUATIONS

A course can be evaluated at any time during or after the term. Evaluations made during the course, called formative evaluations, elicit comments from students so that the professor can make in-course corrections. We like to obtain early feedback immediately after the first test. These evaluations can be as simple as passing out comment cards and asking the students to respond anonymously to two questions such as:

What do you like about this course?

What about this course could be changed to improve your learning?

If you prefer to be a bit more directive and focus the students on their learning, you can replace the first question with the following two questions:

What aspects of this course help you learn?

What aspects of this course interfere with your learning?

Student comments are useful if the professor changes things that are not working. If the comments reveal that the TA is not available during office hours, the professor can take steps to correct this problem early in the semester. The evaluations can also allow the professor to do something he or she wants to do, but which might not go over well without the empowerment of student comments. If one or two students are monopolizing the professor's time in class, other students will likely complain on the comment cards. The professor can then say in a positive sense that he or she has been asked to involve more students in the class.

There are other types of formative evaluation. Chatting with students informally during the semester often points out what is or is not working. Formal weekly meetings with a group of students representing the class is another way of obtaining useful feedback during the semester. Chatting with the TA can also be illuminating since TAs often have a good idea of what is or is not working. Critically evaluating the results of quizzes or tests may show that certain critical concepts have not been learned. The professor may want to adjust the syllabus to provide more time for these concepts. Watching the students' nonverbal behavior and asking them to explain concepts are also types of formative evaluations that can be used in every class period.

Summative evaluations, which are done at the end of the course or well after the course is over, are used for a variety of purposes, some of which are controversial (see Sections 16.3 and 16.5). Of course, summative evaluations provide feedback to the professor. Since professorial self-evaluations are often very high (Centra, 1993), student evaluations can provide a salutary dose of reality. When the professor has excelled, the feedback is a welcome pat on the back.

Summative student evaluations can also be helpful in instructor and course improvement. The more specific the comments, the more useful they are for course improvement. Answers to very general rating questions such as "This is one of the best courses I have ever taken" are not useful for course improvement. Questions on the textbook, handouts, availability of help, homework, tests, lectures, and so forth, can provide the professor with specific areas needing improvement. Based on dissonance theory (when the person's self-evaluation and the feedback received from others differ, dissonance is generated and the person reacts to reduce this dissonance), professors should act to improve their teaching based on student ratings. Unfortunately, many studies have shown little or modest improvement in teaching resulting from the use of course evaluations *alone* (Aubrecht, 1979; Centra, 1993; Lowman, 1985). A meta-analysis by Cohen (1980) shows that there is improvement, but it is modest. Specific questions on student ratings coupled with consultation do improve teaching (Eble, 1988; McKeachie, 1990). Consultation for teaching improvement is discussed in Section 16.4.

Student evaluations, whether formative or summative, are useful because they improve student morale. The chance to register an opinion is helpful even if no one pays any attention. Of course, if it is clear that someone is paying attention and the instructor responds to the comments and improves the course, then student morale will improve even further (Abbott et al., 1990). We collate all the responses, which usually indicates if a concern is widely shared, show the tallied responses to the students in class, and state what we will do to address problems. Although it would be manipulative to give students an opportunity to evaluate courses merely to increase student morale, the increase in student morale when evaluations are used for other purposes is obviously a side benefit.

Administrative use of student evaluations was originally quite controversial (Eble, 1988; Lowman, 1985), especially when salary, promotion, and tenure decisions were involved. As noted earlier, the controversy has decreased, but still simmers because there are continuing difficulties. First, the administration of student evaluations is often done poorly. It is not unheard of for professors to hand out the evaluations and then to throw away poor evaluations before turning them in for scoring. A uniform administration procedure must be used to avoid this or other abuses (see Section 16.3.2). One possible solution is to use a separate rating form for administrative purposes and administer it in a senior seminar course. The actual administration of the evaluation can be done by a staff person or a student representative.

Another solution,that many schools now use is to use online evaluations. Second, many professors do not trust the reliability or validity of student evaluations. This issue can be partly put to rest with scientific data (see Section 16.4). Unfortunately, if the administrator using the evaluations does not understand the effect of extraneous variables, the evaluations can be misused. For example, evaluations of professors in classes with less than fifteen students tend to be quite high. This needs to be taken into account when professors are compared. Third, the specific questions which are so useful for course improvement are not useful for overall administrative evaluations (Centra, 1993). Only the overall course and instructor ratings are useful for this purpose since the overall ratings have the highest correlations with student learning. To avoid inadvertent abuses, only the overall ratings should be sent to administrators and promotion committees. The alternative of a separate rating form for administrative use only would also solve this problem. Fourth, few professors are uniformly excellent or uniformly poor in all types of courses (Murray et al., 1990). Poor ratings may only represent poor casting of the professor in a course. Thus, student ratings over a long time period for a large number of courses are needed.

Evaluation of teaching for administrative use by faculty or chair visits to the classroom is even more controversial than the use of student ratings. Since ratings based on visits by professors not trained in the evaluation of teaching tend to be much less reliable than student ratings, this practice should not be used for administrative purposes. (Faculty visits can be useful for course improvement; see Section 16.5.)

A final use of student ratings is as information for other students who are potential consumers of the courses (Canelos and Elliott, 1985; Marsh, 1984). Some universities have a long tradition of student-run evaluations which are then published in student guides. There is no doubt that these guides do have an effect on the elective courses which students sign up for. The aim of informing the consumer of what an instructor and course will be like is laudable. Unfortunately, student-run ratings/guides and for-profit internet rating services may be poorly controlled (and in effect uncontrollable). It is not unusual for some of the guides to be extremely biased, particularly during periods of political upheaval. Engineering courses are usually not heavily represented in these guides since few engineering students join these student groups and since few engineering courses are electives.

16.3. STUDENT EVALUATION METHODS

Student evaluations are now the most common method for evaluating instruction and one of the most researched items in higher education (Heywood, 2005). Student evaluations are the focus of this section and Section 16.4. Since student evaluations cannot completely evaluate instruction, they should be used in conjunction with other evaluation methods (Section 16.5).

16.3.1. Types of Student Evaluations

If the purpose of the course evaluation is entirely feedback to the instructor for the purpose of course improvement, then informal evaluation procedures can be used. Both formative and summative evaluations can be made with comment cards, either with or without cues to the students on what to focus on. If there are specific questions of interest, the professor can generate a student questionnaire. But for administrative use or for research purposes, professor-generated questionnaires and comment cards are not suitable.

For administrative purposes, global questions on teaching effectiveness should be used since global questions have the highest correlations with student achievement (Centra, 1993). There is an advantage to separating the course improvement and administrative functions of student evaluations, since professors are more likely to use formalized course evaluations if they know they will not be used by the administration.

Many universities use formalized course evaluation procedures often administered by either a separate learning center or a student organization. If paper forms are used, they are usually machine-scored, multiple-choice questionnaires with space available for student comments. Online evaluation forms are similar except the students have to log in to access them. Perhaps because of this additional barrier, the response rates for online evaluations are lower than when evaluations are done in class. Many professors give a small amount of points or provide other inducements to encourage students to fill out the evaluations. The students usually rank a variety of questions on 4 to 7-point scales. Usually both specific items such as "The textbook was well written and understandable" and global ranking items such as "Overall, this course ranks highly" are included in the questionnaire. The forms may allow for instructor selection of items from a large pool, and it may be possible for the instructor to add additional items. Marsh (1984) notes that since good instruction can have many dimensions, the forms must be multidimensional, that is, many different aspects of instructional ability need to be considered.

A large number of course evaluation forms have been developed and are available for a nominal fee. If student evaluations are to be used for research purposes the form needs to be carefully designed (Marsh, 1984). Many of the commercially available forms are adequate, and no form has been shown to be superior, which is why many different forms are in use.

16.3.2. Administration of Student Evaluations

Several studies have shown that the way student evaluation forms are administered can affect student ratings (Aubrecht, 1979; Centra, 1993; Marsh, 1984). Professors who make verbal comments requesting high rankings because of their importance in promotion and tenure decisions may well get higher rankings, particularly if the comments are subtle instead of blatant. There is also a built-in bias if the professor is present when the students fill out the evaluation forms. In addition, professors, like students, are subject to human frailty, and have been known to cheat occasionally.

To avoid these problems a uniform procedure for administering student evaluations should be used. The professor should not be present when students are filling out the forms. A trustworthy administrative assistant, TA, or even the department chair should administer the evaluations. A standard procedure such as the following should be followed for paper forms:

1. Bring in the forms and pencils needed.
2. Announce to the class why he or she is there and state that it is departmental policy that the professor not be present.
3. Describe the purpose of the forms, state what they will be used for, and note that evaluations are important and need to be done carefully.
4. Distribute the forms and pencils.

5. Give simple instructions. Be sure to note that 1 is high (or low).
6. When all the students are finished, collect the forms and put them into an envelope. Seal the envelope.
7. Deliver the envelope to the agency which scores the forms.

What should be done with the results of the evaluations once they have been scored is somewhat controversial. Certainly they should be provided to the professor for course improvement. Professors should be encouraged but not forced to discuss their evaluations with another professor or an instructional consultant. They should also be encouraged to discuss the ratings and an improvement strategy with the class, since this increases the students' satisfaction (Abbott et al., 1990). The use of voluntary evaluations for administrative purposes can cause problems if norms are reported. Since those who volunteer are mainly professors who are most interested in teaching and who are good at teaching, the norms are skewed to high rankings. For administrative uses a required rating of all the professors in the department is preferable.

16.4. STUDENT EVALUATIONS: RELIABILITY, VALIDITY, AND EXTRANEOUS VARIABLES

Many faculty members complain that student evaluations do not mean anything, are not reliable, students can be bought with grades, the ratings are not valid, alumni should do the rating, and so forth. Unfortunately, engineering professors who would never dream of doing an engineering design without data are willing to complain about student evaluations with no data. In this section a sampling of the available scientific data that allows one to discuss these complaints rationally will be presented. Before discussing the questions of reliability, validity, and extraneous variables in detail, we will note that the complaints are somewhat misplaced. Students are generous evaluators. For example, in one study only 11% of 852 engineering classes were rated as below average (Centra, 1993).

16.4.1. Reliability of Student Ratings

Reliability of student ratings means that they are consistent for whatever it is they are measuring. The internal consistency (the agreement of students in the same class) of student ratings is quite good and becomes excellent as the number of students doing the rating increases. Aubrecht (1979) reports the following correlation coefficients:

$r = 0.69$ (ten students)

$r = 0.81$ (twenty students)

$r = 0.89$ (forty students)

Marsh (1984) reports correlation coefficients that are slightly higher:

$r = 0.6$ (five students)

$r = 0.74$ (ten students)

$r = 0.90$ (twenty-five students)

$r = 0.95$ (fifty students)

A second measure of reliability is stability. Are the raters stable over time and are the professors stable over time? The correlation coefficient for students in 100 classes when they were asked to rate the class after it was over and at least one year later was r =0.83 (Marsh, 1984). When the same instructor was evaluated for the same course but in different years (which means different student raters), the correlation coefficients varied from r =0.62 to r = 0.89 with a mean value of r_{mean} = 0.74 (Marsh, 1984; Murray et al., 1990). Thus, we can conclude that both student raters and professors teaching the same course are stable.

Professors are probably not equally proficient at teaching all courses. When the same instructor was rated in the same year in different courses, the correlation coefficients varied from r = 0.33 to r = 0.55 with a mean value of r_{mean} = 0.42 (Marsh, 1984; Murray et al., 1990). These correlation coefficients are significantly lower than those obtained for the same instructor teaching the same course. This result is discussed in more detail at the end of Section 16.4.3.

16.4.2. Validity of Student Ratings

Validity means that student ratings are measuring what they are supposed to be measuring. Do student ratings actually measure teaching quality? This is a much harder question to answer than questions of reliability, but sufficient research reports are available to say yes.

Critics of student ratings often claim that student achievement is the outcome that we should study. Do student ratings correlate with student achievement? There is broad agreement in the literature that a reasonably strong positive correlation exists between student achievement and student ratings (Aubrecht, 1979; Centra, 1993; Cohen, 1981; Greenwood and Ramagli, 1980; McKeachie, 1990; Marsh, 1984; Svinicki and McKeachie, 2014). The conclusive study was the meta-analysis of Cohen (1981) who looked at all available studies relating student achievement and student ratings in courses with multiple sections taught by different instructors. The global ratings were highly correlated with the final examination scores. Cohen (1981) found correlation coefficients of r = 0.50 based on questions about instructor skill, r = 0.47 based on questions about the global rating of the course, and r = 0.43 based on questions about the global rating of the instructor. Thus, sections where students learned more rated the instructor and the course higher than sections where students learned less.

Student ratings have modest positive correlations with other methods of evaluating instruction. The correlation coefficients between student ratings and ratings by professors ranged from r = 0.60 to r = 0.70 if the professor had not visited the classroom (Aubrecht, 1979; Marsh, 1984). The correlation between student ratings and administrator ratings where the administrator had not visited the classroom was r = 0.47 (Aubrecht, 1979). If the colleague had visited the classroom before rating the instructor, then the correlation coefficient with student ratings was r = 0.20 (Aubrecht, 1979; Marsh, 1984). This number is low partially because the reliability of ratings based on colleague visits is low (see Section 16.5). When professors did not visit a colleague's classroom, they apparently based at least part of their ratings on discussions with students. Thus, these ratings correlate significantly higher than those based on visits.

The correlation of professors' self-rating of their teaching ability with student ratings has been extensively studied. Correlation coefficients between student ratings and a general instructor self-rating are about r =0.19 (Greenwood and Ramagli, 1980). When the instructors do a self-rating for a specific course, the correlations with student ratings are significantly higher, $r = 0.45$ to $r = 0.49$ (Marsh, 1984). Most professors rate themselves higher than the students do, and about 30% of the time significantly higher.

Factor analysis has been used to determine what students are rating. The results of these studies show that students do not just give a single global rating but include several factors. Aubrecht (1979) states that a typical breakdown of factors with the most important factor first is:

1. *Skill*. Interesting presentation, intellectual stimulation, clarity.
2. *Rapport*. Concern for students, classroom interaction.
3. *Structure*. Organization, course preparation.
4. *Difficulty*. Amount of work demanded.

A similar but more detailed list of seven factors is given by Marsh (1984):

1. *Learning and value*. Challenge, subject interest, amount of material learned.
2. *Enthusiasm*. Interest, humor.
3. *Organization*. Objectives, clear explanation.
4. *Group interaction*.
5. *Individual rapport*. Provides help and answers questions.
6. *Breadth of coverage*.
7. *Examinations and grading*.

Wilson's (1972) list includes the first five factors given by Marsh. Higgins et al. (1991) prepared a list of the characteristics of good instruction by asking their engineering students to generate such a list. Their list was similar to the other lists, except the students added: good communication and pronunciation, real-life applications and analogies, and lots of examples.

Gall et al. (2003), in a study of 181 mechanical engineering classes, found that the items most highly correlated with the course and instructor ratings were *fairness* and *accessibility*. The authors interpreted accessibility as a combination of *availability* and *approachability*. Accessibility is related to rapport in the lists of Aubrecht (1979), March (1984), and Wilson (1972). Methods instructors can use to increase accessibility include an open door policy, evening help sessions before exams, learning and using the students' names, obtaining feedback from students often, and having lunch with students (Gall et al., 2003).

Students rate by reasonable criteria for good teaching. Their ratings also agree with the two-dimensional model of good teaching presented in Chapter 1.

16.4.3. Effects of Extraneous Variables on Student Ratings

Critics attack the validity of student ratings because of the effect of extraneous variables. They state that ratings are affected by the time at which the class is taught, who is taught, the grades given, the class size, the type of course, the age and gender of the professor, and so forth. This attack is partially correct since extraneous variables do affect student ratings, but the effect is usually quite small and is not enough to make a good teacher look poor, or vice versa (McKeachie, 1990). In this section we will explore what Marsh (1984, p. 730) calls "the witch hunt for potential biases in students' evaluations."

Student Focus While Doing Evaluations. Student evaluations will be less reliable and valid if the students do not focus their attention on the evaluation (Williams, 2003). Under what conditions do students pay attention to the evaluations and give their best efforts? If the students believe that their evaluations will make a difference and help improve the teaching or the course, they are motivated to provide the feedback (Giesey et al., 2004). Professors can prime the students' motivation by briefly discussing how course evaluations have been used in the past to improve teaching or the course.

Initial Student Motivation and Expectations. Students who expect a course to be good often find this to be true (Svinicki and McKeachie, 2014). Since students often choose electives because they think the course will be good, electives often receive high ratings. The correlation between the student's initial liking for the subject and the student's rating of the course at the end of the semester ranges from $r = 0.42$ to $r = 0.49$, which is quite high (Aubrecht, 1979). Student enthusiasm and prior interest account for much of the background or extraneous variable effect (Marsh, 1984). Initial student motivation is such an important variable that in the IDEA system for teacher evaluation, initial student motivation is used in combination with class size to establish norm groups for comparison purposes (Aubrecht, 1979).

Class Size. The second most important extraneous variable is class size, but the correlation coefficients are significantly less than for initial student motivation. With fewer than fifteen students in a class, the ratings are significantly higher than they are otherwise. Students enjoy the close personal contact with the professor and with other students, which is almost automatic in classes this small (Centra, 1993). As the class gets larger the ratings decrease and the correlation coefficients obtained are generally from $r = -0.10$ to $r = -0.30$ (the correlation is negative since ratings are smaller for larger classes) (Aubrecht, 1979; Koushki and Kuhn, 1982). Johnson et al. (2013) studied engineering courses only and found r = −0.291. For very large classes (more than 200 students), several studies show that ratings go back up (Marsh, 1984; Koushki and Kuhn, 1982). This may occur because departments assign their best teachers to large classes. Johnson et al. (2013) did not see this effect, but they did not report their maximum class size. Note that some studies have found no effect of class size in engineering courses (Canelos and Elliott, 1985; Ratz, 1975). In engineering the class size effect, if there is one, may be confounded by course type (discussed below). Most large engineering courses are required courses, which receive lower ratings than elective courses.

Academic Field. There are small but significant effects based on the academic discipline when all other variables are controlled. Aubrecht (1979) reported that humanities, fine arts, and language had slightly higher rankings than social or physical sciences, mathematics, and engineering. Koushki and Kuhn (1982) found that at Clarkson University the arts and sciences and industrial distribution had slightly higher ratings than either engineering or management. Although there is not complete agreement between these studies, they do agree that engineering students give ratings at the low end of the spectrum. Thus, cross-field comparisons are somewhat difficult. Bianchini et al. (2013) hypothesized that students who are satisfied with their degree program are more generous in their instructor ratings.

Course Type. Engineering professors commonly believe that laboratory courses receive low ratings. Kuriger (1978) found that this was indeed true and that laboratory courses had much lower ratings than classes dispensing theory. Kuriger (1978) also found that engineering elective courses had better ratings than required courses in the engineering discipline, which had higher rankings than core engineering classes taken by students in a number of engineering disciplines. Koushki and Kuhn (1982) also found that electives and courses in the discipline had higher ratings than core courses, but they did not observe a difference between elective and required courses in the discipline. Johnson et al. (2013), on the other hand, did observe higher ratings for electives than for required courses. Instructors teaching service courses for students in another discipline received lower ratings (Ratz, 1975). The hours that the class meets also makes a small difference, with classes meeting at the convenient times of midmorning and midafternoon receiving the highest rankings (Koushki and Kuhn, 1982).

Course Level. Johnson et al. (2013) found fairly complicated results for the effect of engineering course level. More experienced faculty received statistically significant higher ratings in first year engineering courses, but statistically significant lower rankings in junior and senior courses. Seniors and graduate students rated classes slightly higher than other students even when the type of class was the same (Kuriger, 1978).

Grades and Course Workload. A common criticism is that professors can buy ratings by requiring very little work and by easy grading. The first hypothesis is clearly wrong. Studies show that students rate courses with high workloads higher than courses with low workloads (Marsh, 1984). Dee (2007) found the same result in engineering courses. However, Gall et al. (2003) found that for instructors with average or low accessibility, high workloads lowered the ratings, but this result was probably not statistically significant. The effect of grades is much more complex. Grades earned previously from the same instructor do not affect ratings in the course (Canelos and Elliott, 1985). Although Kuriger (1978) found a negligible correlation between grades and ratings in engineering courses, Johnson et al. (2013) found a positive correlation. Pooled studies over many classes in a number of different disciplines show correlation coefficients between expected grade and ratings ranging from $r = 0.1$ to $r = 0.3$ (Aubrecht, 1979). However, one needs to be careful not to confuse correlation with causation. When the studies are controlled for prior interest in the subject and for the effect of workload in the course, most of the correlation disappears (Marsh, 1984). What remains is mainly from students who are receiving A's. Marsh (1984) discusses three possible hypotheses for the remaining slight effect of expected grade on course rating. These hypotheses are:

1. *Grading leniency*. The students rate the course higher because they expect a grade higher than they have really earned. There is no empirical evidence for this hypothesis.
2. *Validity*. Students who learned more received higher grades and rated instructor higher.
3. *Student characteristics*. Students who earn better grades have some characteristic that leads them to rate the course higher. This is correlation without causation.

Professors. A large number of professor effects have been studied. Kuriger (1978) found that professors who had won teaching awards received significantly higher rankings than professors who had not. This is no surprise and represents another sign of the reliability of student ratings. Kuriger (1978) also found that professors received better ratings than American TAs who had higher ratings than foreign TAs. Presumably, the professors are more experienced. However, younger professors do better than older professors (Canelos and Elliott, 1985; Bianchini et al., 2013), and professors receive lower ratings as they become more experienced (Bianchini et al., 2013; Johnson et al., 2013). Wilson et al. (2014) in a study of psychology students found that students expected younger professors to be friendlier, have more rapport, encourage questions more, and be more attractive than older faculty. Older professors were expected to be more likely to require good work and give the students too much work than younger professors. Ratz (1975) found that the first time a professor teaches a course ratings are lower than later offerings. By a slight amount, associate professors received the highest ratings, but this disappeared when only electives were considered (Kuriger, 1978). Tenure track faculty received higher ratings and awarded higher grades than non-tenure track faculty (Bianchini et al., 2013; Johnson et al., 2013). Bianchini et al. (2013) speculated that full professors and non-faculty instructors receive the same low ratings because they both have a significant amount of extra-academic activities. Students react positively to very expressive teachers, and these teachers may get overly generous ratings (McKeachie, 1990). However, one of the items that students consider a constituent of good teaching is enthusiasm, and expressiveness is interpreted as enthusiasm. McKeachie (1990) found that neither the gender of the instructor nor the knowledge of the subject matter affects the ratings. However, Johnson et al. (2013) found that female engineering faculty received small, but statistically significant lower rankings in first year and sophomore courses than male faculty. For courses after the sophomore year there were no statistically significant differences based on gender. The question of how the professor's research affects teaching ability and ratings is discussed in detail in Section 17.4.

Instructor Personality. Murray et al. (1990) did an interesting study on the interactions between the professor's personality and the type of course. Their most important conclusion is that few professors are good teachers in all types of courses and few teachers are poor teachers in all types of courses. Casting the professor in the appropriate type of course is important. The authors suggest that professors should determine what type of course they do well in and then stay with that type of course as much as possible. The three general categories of courses that were clearly different were introductory and general courses held in large lecture halls, junior- and senior-level electives that were much smaller discussion classes, and methodology courses that were very work-intensive. Professors who were extroverts, yet compulsive enough to handle the details of large classes, received high ratings in the large lecture classes. Professors who were extroverted, friendly, and supportive yet flexible received high ratings in the discussion classes. Ambitious, competent, hardworking, and confident professors did well in the methodology courses. The only personality trait which correlated with high ratings in all categories of courses was leadership, which they defined as taking initiative and getting things done. This study involved psychology courses and may not generalize to other fields. In a separate study Sherman and Blackburn (1975) found that instructor pragmatism was positively related to ratings in natural science courses but not in courses in humanities or social sciences. Instructor amiability was related to ratings in humanities but not in natural or social sciences. From this one could hypothesize that pragmatic instructors would receive higher ratings in engineering courses.

Conflicting Results. We have reported some results that conflict with each other. In addition to the possibility of errors, there are several reasons why results may differ. First, the student groups are different. Because engineering students and students at any single college self-select into the program, they can be expected to have different characteristics than other student groups. Second, the ranges of variable may be different. For example, the slight increase in ratings observed for very large classes occurred for more than 200 students (Marsh, 1984; Koushki and Kuhn, 1982). Studies that did not see this effect either had fewer than 200 students per class (Ratz, 1975) or did not report the number of students (Johnson et al., 2013). Third, an effect may be observed either without controlling for other variables or after controlling. Initial student motivation and expectations are an important variable that most studies do not include. Fourth, there is a tendency to report striking results even if they are not statistically significant. These findings should be ignored until they can be replicated.

16.4.4. Can a Professor "Buy" Student Ratings?

Yes, a professor can "buy" student ratings by two different methods. First, the professor can load all the extraneous variables in her or his favor. Thus, the professor could arrange to teach a small, non-laboratory, elective class to seniors and graduate students. The course would be scheduled at a convenient time, and the TA would be from the United States. If possible, the students would be initially interested in the material. The professor would give A's to all the students on the A-B border. This set of conditions can buy a slightly higher rating, but it cannot turn a poor teacher into a good one.

The second approach is to present material clearly and communicate with the students. Organize the material and give clear objectives. Follow a logical presentation scheme with a minimum of tangents. Present many examples and real-life applications. Cultivate a pragmatic, let's-get-things-done attitude. Show enthusiasm, interest, and a love for the subject. Stimulate the students intellectually and have a significant breadth of coverage. Be readily accessible both in and out of class. Have a sense of humor. Use a good textbook that is integrated into the course. Arrange matters so that the workload is high, but not unreasonably so. Have fair examinations and a clearly defined grading system. Encourage group interactions both within and outside the class. Develop a team concept with the students—a team whose job it is to learn the material. Keep the students active and incorporate a variety of modes of presentation. If you do all these things, then you will have done a good job and will have earned the high ratings you will receive.

16.5. OTHER EVALUATION PROCEDURES

Student evaluations, though useful, are neither the sole nor the best way to evaluate a course. They miss, for example, the richness of ideas that can be obtained with interview techniques, and students are not qualified to evaluate content. A combination of techniques can make up for the deficiencies of student ratings. Hoyt and Pallet (1999) recommend that student ratings account for 30 to 50% of the overall instructional rating. Colleague ratings of specific courses would be another 25 to 35%, colleague ratings of indirect contributions to the instructional program 10 to 15% and the department head's ratings of indirect contributions 10 to 15%. Few schools have an organized program similar to this.

The ratings on indirect contributions to the instructional program would rate the professor's contributions in the following three areas (Hoyt and Pallet, 1999):

1. General learning environment. Does the faculty member enrich the general environment by being generally positive and friendly to both faculty and students? Does the faculty member engage in general conversations about teaching and curricular matters?
2. Course and curricular development. Does the professor regularly update and upgrade her courses? Is she involved in departmental curricular revisions?
3. Helping other professors in teaching. Does the professor share his syllabus and other materials? Is he mentoring any faculty members in teaching? Is he involved with the training of teaching assistants?

All departments should include these components in determining teaching contributions.

Student interviews can be a much richer source of information than student ratings, but they are time-consuming. Interviews should not be done by any of the professors being evaluated. If the department chair and or the director of the undergraduate program can arrange to do exit interviews of all the graduating seniors, a significant amount of information can be obtained about the performance of professors, the curriculum, and miscellaneous items. Except in regard to courses the students have taken recently, the information is not likely to be specific enough to help professors improve courses. Thus, the interviews should supplement course evaluations. For valid information to be obtained on a professor, a high percentage of the students need to be interviewed; otherwise, only students with complaints may come in. Although the main advantage of interviews is that students have the freedom to bring up whatever they want, some structure helps control the time and ensures important topics are covered. Setting a time limit in advance helps the interviewer structure the interview and control time. Exit interviews are also useful for ABET review of the program (see Section 4.7).

An alternative to individual student interviews that takes much less time is the Small Group Instructional Diagnosis (SGID) method (Abbott et al., 1990 ; Angelo and Cross, 1993; Bowden, 2004) in which a facilitator and the instructor first meet to discuss the course. The facilitator then meets with the class in the absence of the instructor and forms small groups which discuss the strengths of the class, areas requiring change, and recommendations for change. Each group reports to the class, and the facilitator collects and summarizes the reports for the class. He or she then clarifies the ideas until the class agrees that the summary is accurate. This class meeting can take place in a single fifty-minute period. The facilitator and the instructor then meet to discuss the students' concerns and recommendations. A strategy for improving teaching is developed. The instructor returns to class and extensively discusses the facilitator's report and the proposed improvement strategy. Of the methods tried, students preferred the group interview procedure to the use of standardized rating forms. With either the group interview or standardized rating forms, students were more satisfied when the instructor responded extensively to the student evaluations (Abbott et al., 1990). The SGID method is also useful for TAs who are in charge of recitations or courses (Bowden, 2004). Instructors who are interested in improving their teaching should contact their institution's teaching improvement or learning center to see what services are available.

Self-ratings by instructors are useful for course improvement, although the correlations with student ratings are low. Since many faculty rate themselves high, with 30% significantly higher than the students' evaluations, self-ratings should be used as only one part of the course evaluation system. The high self-assessments should be no surprise since most people routinely rate themselves highly (Dunn et al., 2004). Instructors are more realistic in their self-ratings when they focus on a specific course. Use of some type of questionnaire such as the course evaluation guide developed by Lindenlaub and Oreovicz (1982) helps to ensure that the instructor has not missed any important areas. Course improvement is highest when the self-evaluation is discussed with a supportive but critical consultant. This is particularly true regarding the pace of the course and the workload. Natural science professors typically underestimate the pace and workload (Greenwood and Ramagli, 1980), and engineering professors probably do also.

Faculty evaluations of teaching are another approach (see also Section 16.4.2). Unfortunately, most professors are not trained in classroom observation, and the correlation coefficient between the ratings done by different faculty raters after visits is $r = 0.26$ (Marsh, 1984), which is quite low. Despite this, peer visits are useful since the professor visiting the class is likely to provide some feedback, both positive and negative, that the students do not. Course portfolios (Section 16.7) are a teaching improvement method that includes peer review. Student evaluations are much more reliable than faculty evaluations, possibly because the students see the professor many more times than a professor visiting the classroom does.

Administrative ratings are similar to faculty ratings (Greenwood and Ramagli, 1980). An administrator often bases her or his ratings on informal information gathered from students. Untenured professors in particular are likely to be intimidated by an administrator visiting their classroom. The advantage that department heads have is that it is part of their job to help young faculty improve their teaching, and many young faculty members report that such a person was the only professor with whom they had discussed teaching (Boice, 2000).

A systematic follow-up of alumni is appealing. Many professors argue that the alumni are older and wiser, have a feel for what is important in industry, and rate professors differently than students. However, alumni follow-ups routinely result in very high agreement with ratings by current students (Canelos and Elliott, 1985; Centra, 1993). Since evaluations from current students are cheaper, easier, and result in a higher rate of usable returns, few schools use alumni ratings of professors.

Many critics of student evaluations claim student learning or student achievement should be analyzed. As noted in Section 16.4.2, there is a positive correlation between student ratings and test scores. Although direct measurement of student learning to evaluate courses may be preferable, it is difficult (Centra, 1993; Greenwood and Ramagli, 1980). Should it be the increase in knowledge or the total knowledge that counts? Should the learning of the better or the more poorly prepared students be counted differently? The better-prepared students will probably score higher on tests but may learn less new material than students with poorer preparation.

In addition, some type of standardized test or concept inventory would have to be used. Instructor-prepared tests may be written to cover what the instructor thinks students know, or the instructor may teach to the test if he or she knows what is covered on the exam. This biasing of the results may well be unintentional. Measures of learning should include the affective domain. Most professors and students would agree that a course in which students learn the material but hate it is not a good course.

Despite these problems with the direct use of student learning for the evaluation of teaching, it should be used to supplement other evaluation methods. In particular, student learning should be used for course improvement. Tests should be analyzed first for discrimination (see Section 11.3.2) and then to see if there are topics which students are not learning. If there are, then extra time or a different teaching strategy is needed. Once the problem areas have been pinpointed, the problems and possible solutions should be discussed with another professor. Often professors try to teach too much material, and the easiest way to increase student learning is to cover less.

Classroom observations or classroom assessment can also be used to determine what the students in a classroom are learning (Angelo and Cross, 1993). One assessment technique is “one-minute papers.” Toward the end of the class ask the students: (1) What is the most important thing you learned today? or (2) What questions do you still have? Not only do minute papers require the students to be active and construct their own knowledge, but they also provide useful feedback to the instructor. A perusal of the students’ responses may show where your message is not getting across.

Finally, the suitability of the content covered in the course needs to be judged by peers from academe or industry. Students who are learning the material cannot judge if they are learning the right or most useful material (Centra, 1993). One advantage of ABET visits is that content is evaluated, albeit by only one person. In general, new professors with no industrial experience are likely to be too abstract. Professors heavily involved in research are likely to put too much of their research in courses. Older professors who are doing neither research nor consulting may be presenting obsolete material. A professor who won a best teaching award did so even though a later examination of his materials showed that the material was obsolete.

16.6. TEACHING IMPROVEMENT

Course improvement is much more likely if student ratings are shared with a consultant, probably because it is much harder to avoid the signals that improvement is needed. Without a consultant most professors either rationalize the ratings or "just try harder." The consultant helps the professor focus on an action plan to solve the problems pointed out in the ratings. The consultant can make specific suggestions of what to try and can also be supportive. A specific development plan with informal follow-ups can be developed for the remainder of the semester or for the next semester. We recommend that the consultant be an interested professor in the same department or a staff member of the teaching improvement center. Professors have the advantage that they will understand the constraints the professor is acting under and will not make recommendations which are impossible. On the other hand, consultants from the teaching improvement center are likely to be more experienced in helping professors improve. Svinicki and McKeachie (2014) suggest that there is no reason to wait until the end of the semester to administer the evaluation form. The student evaluation can be useful for course improvement in the current semester if it is administered from the third to the fifth week of the semester.

Visits in class can be a natural extension of consultation since they give the instructor and the consultant more to talk about. Although there are advantages to an unstructured procedure during visits (Elbow, 1986), correlation coefficients are likely to be higher if a structured procedure is followed. Sheppard et al. (1998) developed protocols for visits to engineering classrooms. Andrews and Barnes (1990) discuss several of the highly structured instruments that are used for evaluating primary and secondary schools.

Video has some application in course evaluations, particularly in considering some of the performance aspects of teaching (Centra, 1993). However, the presence of a video camera in the classroom can inhibit both professor and students. The result is a somewhat artificial class which will not be completely representative. Elbow (1986), suggested that if a video is shown to a consultant, the professor should pick one that the professor is satisfied with. We recommend video recording once so that you can watch for annoying mannerisms.

An unstructured conversation—letting the person just talk about teaching—can be very useful in providing insights (Elbow, 1986). An unstructured conversation can also be pleasurable since many professors enjoy talking about teaching. Hoyt and Pallett (1999, p. 4) are adamant about the need for assistance, "What is clear from experience is that lasting improvements are almost never made without some kind of active assistance from another person."

Teaching portfolios are a self-rating method that is most useful for teaching improvement. Seldin et al. (2010) recommend that professors develop their teaching portfolios in conjunction with a knowledgeable colleague or consultant. The teaching portfolio includes representative teaching materials such as syllabi, assignments, tests, and other handouts. Most importantly, the professor needs to reflect on what these materials are supposed to accomplish and what changes should be made to improve teaching. The teaching portfolio should also include evidence of teaching effectiveness including student evaluations, comments from consultants or colleagues who observed the professor teaching, and a list of teaching awards or other honors. Teaching portfolios often lead to improved teaching because the professor invests a significant amount of time developing the portfolio and the required reflection is often insightful.

Course portfolios are closely related to teaching portfolios, but focus on single courses and include peer review (Bernstein et al., 2006; Peer Review of Teaching Project, n.d.). Course portfolios encourage instructors to reflect analytically about their teaching and student learning in a particular course. For a benchmark course portfolio the instructor typically reflects on the syllabus, course goals and the reasons for these goals. Next the instructor explores the instructional practice including teaching methods and course materials chosen to help the students learn. Finally, the instructor analyzes samples of student work to explore in depth what students learn and how learning is assessed. Learning and assessment should be, but often is not, logically connected to the course goals and learning objectives. Benchmark course portfolios help instructors frame more specific questions that they will explore with an *inquiry* course portfolio. In an inquiry portfolio instructors first frame the issue to be investigated. The instructor then develops and describes a methodology to investigate the issue and applies the methodology. Finally, the findings are analyzed and assessed. Course portfolios are externally reviewed by peer review teams in an approach that is similar to external peer review of papers submitted for publication.

If engineering colleges become serious about improving teaching, the wealth of experience from primary and secondary schools should be used to show what does and does not work. The way to turn around poorly performing primary and secondary schools is to find a new principal. To turn around a college department with poor teaching, find a new department head.

16.7. CHAPTER COMMENTS

The style in this chapter differs from that of previous chapters in that we have tried to cite all our facts. This was done because of the controversial nature of evaluations of teaching. We wanted to be sure that our facts were backed by the research literature on evaluating teaching, and that skeptical readers could check our sources.

We are in favor of student evaluations and other methods of evaluating teaching since we believe that they help improve teaching. Naturally, all these methods could be improved. However, there does not seem to be a justification for not evaluating teaching just because improvements are needed. There is clearly enough empirical evidence to show that student evaluations separate good teachers from poor teachers. On the other hand, there is also evidence that student ratings cannot make fine distinctions between teachers.

HOMEWORK

1. Informally discuss your teaching with a colleague.
2. Make arrangements to visit the class of a master teacher and afterwards discuss teaching.
3. Develop a simple formative evaluation instrument to use in your classes.
4. Obtain a copy of your university's summative form for student evaluations. Evaluate the evaluation form. Is it adequate? If not, how could it be improved?

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CHAPTER 17

PROFESSIONAL CONCERNS

Professors have a variety of professional concerns, from obtaining tenure to professional growth, which directly or indirectly affects their teaching. Matters of faculty development for a successful and enjoyable career confront them with responsibilities of professional ethics and the necessity that they be ethical professionals. After first considering how faculty members actually spend their time, the sections that follow will deal with these matters in turn.

In this chapter we are reporting the situation as we see it, not as we wish it would be. We believe that both education and research are important, but education and the welfare of students should be the primary activity and focus of the university. What we see at most research universities is the reverse.

17.1. SUMMARY AND OBJECTIVES

After reading this chapter, you should be able to:

- Explain tenure and the usual procedures for promotion and tenure at universities.
- Discuss the environment for engineering faculty and ways to improve it.
- Discuss methods for developing faculty and prepare a personal development plan.
- Outline the AAUP ethical standards and determine if the AAUP guidelines are satisfied.
- Determine the applicability of Hougen's principles in one's own engineering discipline.

17.2. FACULTY TIME

How many hours per week do faculty work? Bowen and Schuster (1986) and Fairweather (1996) report that studies typically find that professors work 55 to 62 hours per week during the academic year and slightly less during student vacation periods. Beaufait and Harris (1989) state the norm for new faculty is about 55 hours per week. A 2010 survey at the University of Michigan found the mean hours per week of respondents was 58.4, which was an increase

Table 17-1. Percentage Faculty Time Per Week on Various Activities for Faculty at all Four Year Institutions from 2007–08 Survey (Higher Education Research Institute, 2009)

Activity	Hours per week						
	None	1–4%	5–8%	9–12%	13–16%	17%+	Median h/wk
Scheduled teaching, Female	0.7	11.8	30.1	35.4	13.6	8.5%	9–12
Scheduled teaching, Male	0.6	14.5	32.0	35.0	11.1	6.8	9–12
Preparing to teach & grading, Female	0.3	7.9	21.9	23.4	16.0	30.5	9–12
Preparing to teach & grading, Male	0.3	11.9	25.1	25.3	15.6	21.8	9–12
Research & scholarly writing, Female	19.1	36.9	19.1	11.1	5.1	8.7	1–4
Research & scholarly writing, Male	13.2	29.3	20.8	13.5	7.5	15.6	5–8
Committee work & meetings, Female	4.1	55.2	28.2	8.3	2.6	1.7	1–4
Committee work & meetings, Male	5.7	58.5	25.4	7.0	2.1	1.3	1–4

from the 57.2 recorded in 1996 (Wright, 2011). How do faculty split their time between teaching, research and committee work? Table 17-1 shows the results from the 2007-08 Higher Education Research Institute at UCLA survey.

Table 17-1 shows that on average female professors spend less time on research and scholarly writing than do males. Although the median number of hours/week is in the same range, female professors spend more hours per week than male professors in scheduled teaching, in preparing to teach and grading, and in committee work and meetings. Both female and male professors spend less time doing research than they do in teaching activities. The University of Michigan study (Wright, 2011) reported all ranks spent 46% of their time teaching and meeting with students versus 29% on scholarship and research. Assistant professors spent more time per week and higher percentages of their time in both teaching and scholarship than other ranks. To some extent assistant professors were protected from university service, which allowed them to spend less time on service. Menges (1999) found that new faculty spend more time on teaching than do more experienced faculty. At research universities new faculty spent approximately 35% of their time on research and 35% on teaching. At other institutions two-thirds or more of new faculty time was spent teaching. Service commitments started very low but had increased significantly to 10 to 15% of faculty time by the third year. At many research universities new faculty are assigned one course a semester. Based on Boice's (2000) data on time spent by new faculty, the time spent on this assignment is typically:

- 3 h/wk in class plus 20 minutes/day interacting with students before and after class (total = at least 4 h/wk)
- 9–15 h/wk preparing for class, plus another 1–2 h/wk grading. (total = at least 10 h/wk and sometimes 20h/wk
- 3–6 h/wk for office hours, and more if have an open door policy
- Total = 16 to 30+ h/wk

New faculty who have already learned how to teach will be at the low end of this estimate.

17.3. PROMOTION AND TENURE

We will first consider the pros and cons of tenure and then discuss promotion procedures along with the widely perceived criteria for promotion. Finally, we'll consider appropriate actions for untenured professors desiring to be promoted.

17.3.1. Tenure

Tenure is close to a lifetime guarantee of a job as long as the university continues to teach the subject and as long as the professor is not found guilty of any heinous crime. Tenure was invented to protect a faculty member's right to say things in her or his area of competence (Segal, 1974). This right is now called "academic freedom." Prior to the development and widespread adoption of tenure it was not unusual for a professor to be "summarily dismissed" for saying something that the president or board of trustees of the institution disliked. Clearly, the American Association of University Professors (AAUP) was reacting to abuses when its 1915 Declaration of Principles was adopted. Amended in 1940, this declaration advocates:

1. Bestowing tenure on all associate and full professors.
2. A probationary period with a maximum length of seven years.
3. Explanation of the grounds for dismissal.
4. Written notification and a hearing before a faculty committee prior to dismissal.

Most universities use the AAUP guidelines as the basis for their individual variations of tenure.

Tenure has proven to be the best protection for academic freedom. There are numerous instances of abuses by institutions, but sanctions established by the AAUP are embarrassing to the institution and do force most institutions to use due process for tenured professors, a protection not enjoyed by the untenured. Approximately 85% of faculty works at an institution with a tenure system (Higher Education Research Institute, 2009). However, adjunct (aka contingent or temporary) faculty status has effectively removed many professors from the tenure system (O'Meara et al., 2008). Adjunct professors often scrape by on part-time earnings and essentially have no protection from being laid off. Fortunately, engineering continues to hire tenure track professors for most positions.

For some professors the granting of tenure serves to unleash a latent creative ability that can lead to major scholarly advances. The newly tenured professor may feel free to try risky research or to attack the scholarly establishment. Although this flowering does not always occur, the possibility that it might occur is a strong argument in tenure's favor. One additional advantage is that tenure forces the institution to make a carefully considered decision at a defined point in time. Otherwise, many institutions, like many individuals, would procrastinate and not make hard decisions. When the department chair needs to fill out the teaching roster, it would be quite easy to keep someone barely adequate in place.

Like any structure invented in response to abuses, tenure can be abused. First, the process of granting tenure often does not follow the AAUP ideal of faculty control. Even if administrators do not vote or have a limited vote, their presence on committees certainly has an effect on tenure decisions. Of course, the AAUP is an advocacy group, and their ideal may not be in the best interests of all universities.

Perhaps the major charge against tenure is that it inbreeds mediocrity (Segal, 1974). Once mediocre professors become promoted they may promote other mediocre professors and the quality of the entire faculty erodes. As faculty quality slides downhill, the truly excellent professors may decamp. The danger in the tenure decision is that it is at best a guess at a fairly early stage about what a professor will do for the next thirty or so years. If too fine a cut is made, some excellent people may be let go, and they may well bloom elsewhere. If the cut is too easy, mediocre or lazy individuals may be retained.

Tenure often places untenured professors under enormous pressure, while tenured professors are under almost no pressure. This pressure on assistant professors pushes them to do research that is rapidly publishable but not necessarily important. The untenured professor is told to focus and not become a broadly educated scholar. Changing one's research area from one's PhD subject is highly discouraged even if the now older and wiser professor can see more productive research areas. The push for tenure can also severely limit the time an untenured professor spends on improving teaching.

The pressures of tenure also skew the institution's resources. Assistant professors are often given light or nonexistent teaching loads and committee assignments. This is done to let them devote time to research. In the best circumstances this strategy works well, although in the worst circumstances the assistant professor leaves before ever having produced anything. In addition, this procedure may reduce the teaching load below the critical mass necessary for the assistant professor to learn how to become an effective, efficient teacher.

Finally, the very idea of academic freedom can be abused. Academic freedom is meant to protect professors in their areas of competence. There are those who wander outside their areas of competence and still expect to be protected by academic freedom. Occasionally professors teach material totally unrelated to their discipline and argue that it is their academic freedom to do so. Since our colleagues in areas such as biology, climate studies, philosophy, political science, and religion really need the protection of tenure, we are in favor of retaining tenure.

17.3.2. Structure of the Promotion Process

Promotion and tenure systems differ significantly from institution to institution, but the general pattern is similar. We will describe a representative pattern. Untenured professors should determine both the written and the unwritten rules for tenure at their university.

In engineering most new academics are hired as assistant professors on the tenure track. Being on the tenure track means the assistant professor can become tenured, but it also means that if not promoted to associate professor within a specified time frame (usually seven years) the assistant professor loses his or her position. At most institutions, promotion and the granting of tenure occur at the same time. A few institutions promote first and grant tenure later as a separate decision. The next step after associate professor is promotion to professor (aka full professor). There is no set time frame for this promotion. Many schools have instituted named chairs and distinguished professor positions for full professors with outstanding credentials.

Formerly, the promotion process started in the fall. Since many institutions currently ask for letters from eminent researchers, the process often starts in the spring to give time to solicit and obtain letters. The promotion document is prepared by the candidate's department, usually with considerable input from the candidate. The departmental promotion and tenure committee, consisting of the full and sometimes the associate professors in the department, receives a copy of the document. At the spring meeting the committee decides if the candidate should be very strongly considered for promotion. If yes, then letters are requested. In the fall the candidate is fully discussed at the primary committee meeting and the letters are carefully analyzed for hidden meanings. After considerable discussion, a vote, usually by secret ballot, is taken. To have an open and free discussion the committee meetings are totally confidential. Support from the candidate's department and chair is necessary, but not sufficient, for promotion.

If the candidate is successful at the departmental level, the nomination including the letters of recommendation is sent to the next level, which is often the college (such as the college of engineering) level. The department head or a representative makes a presentation to this committee, and another vote is taken. If successful, the nomination is sent to the university level where yet another committee discusses and votes on it. Finally, the nomination is sent to the board of trustees for approval. The board has the legal right to vote no, but fortunately most boards are wise enough to leave promotion decisions to the faculty. By now, it is spring and candidates who are naturally nervous are reduced to quivering jelly.

The details of exactly when this all occurs, who votes, how many votes are required to pass, and so forth vary greatly. Often the only way to find out is to ask.

17.3.3. Criteria for Promotion and Tenure

The criteria for promotion also vary. Although often not written down, time in grade is usually included. Many schools adhere to the AAUP guidelines with promotion being considered during the sixth year so that unsuccessful candidates can be given the seventh year to find another position. Many schools have an unwritten but firm minimum number of years (four or five) required before the candidate will be considered. Since schools have both written and unwritten criteria, an untenured professor is advised to develop a relationship with a mentor (Boice, 2000). The written criteria at most schools include research, teaching, and service. These requirements should certainly be read carefully since they contain some useful information and some nuggets of truth. At research universities the actual criterion for promotion to associate professor and for receiving tenure was previously

RESEARCH / RESEARCH / RESEARCH

this was usually translated into

PUBLISH / PUBLISH / PUBLISH

(Lee et al., 1997; Sisson, 1982; Boyer, 1990). Reporting on a 1989 Carnegie Foundation survey of faculty, Boyer (1990) found that 83% of faculty at research universities agreed with the statement "In my department it is difficult for a person to achieve tenure if he or she does not publish." This number was up from 44% in 1969 and is probably higher now. Among engineering professors 63% strongly agreed with this statement (see Table 17-2). There is an apparent disconnect between promotion and tenure requirements that are heavily based on research while faculty spend considerably more time on teaching related activities than on research (Table 17-1).

Recently, some evidence (Duderstadt and Womack, 2003) has appeared that many schools have revised the unwritten promotion criterion for engineering professors to

PUBLISH / MONEY / ADEQUATE TEACHING

Or more often to

MONEY / PUBLISH / ADEQUATE TEACHING

The addition of two requirements corresponds to a general tightening of the tenure requirements at most universities. The importance of bringing in money is shown in Q3 in Table 17-2. The argument for the need for sponsored research is that professors cannot continue to do excellent research without support, and the peer review process measures quality. Some institutional self-interest may also enter the picture.

The importance of teaching is shown in Q4 in Table 17-2. The results in Q4 probably understate the importance of teaching since the requirement for adequate teaching seems to operate as a minimum condition that must be surpassed but then is not considered further. More recent changes in engineering faculty rewards in the United States were explored by Lattuca et al. (2006). Approximately one-half of the respondents reported that over the past decade there were no changes, approximately one-third reported an increased emphasis on "teaching in faculty hiring, promotion, tenure, and salary and merit decisions," and approximately one-fourth reported a decrease in emphasis on teaching. Interestingly, senior faculty reported more emphasis on teaching in promotion and tenure decisions, whereas untenured faculty thought the emphasis had decreased. This difference in perceptions is important because perceptions of the faculty reward systems influence faculty behavior. Since bad teachers continually cause the department, and particularly the chair, a great deal of grief, the requirement for adequate teaching is clearly in the best interests of the department. Obviously, one can argue with the values that only adequate teaching is necessary; our purpose here is to report what *is*, not what could or should be.

An untenured professor needs to know the details of what counts for how much in the various areas. This search will lead into many subjective areas (Watson, 1991; Wankat, 2002). For instance, not all publications are equal. Ideally, the quality of all publications would be determined by careful scrutiny, but this is a difficult subjective judgment. Boyer (1995) gives guidance on judging the quality of scholarship, but most engineering departments use journals and the opinions of outside experts as a substitute for directly measuring quality. For technical papers, refereed articles in a major (widely available, included in the *Science Citation Index*, and with a high impact factor ["average number of citations received per paper published in that journal during the two preceding years," http://en.wikipedia.org/wiki/Impact_factor]) journal are more important than refereed articles in a minor journal, which are more important than refereed notes, which are more important than articles in refereed proceedings (computer sci-

Table 17-2. Tenure Responses, 1989 National Survey of Faculty (Boyer, 1990)

Responses to statement #1:	Strongly agree	Agree with reservation	Neutral	Disagree with reservation	Strongly disagree
1. In my department, it is difficult for a person to achieve tenure if he/she does not publish					
Research Institution	83	12	1	3	2
Engineering	63	18	7	7	4
Responses to Q2 to Q4:	**Very Important**	**Fairly Important**	**Fairly Unimportant**	**Very Unimportant**	**No Opinion**
Q2. How important is the number of publications for granting tenure in your department?					
Research Institution	56	39	4	1	1
Engineering	43	40	10	5	3
Q3. How important are research grants received by the scholar for granting tenure in your department?					
Research Institution	40	36	16	6	2
Engineering	49	28	17	4	2
Q4. How important are student evaluations of courses taught for granting tenure in your department?					
Research Institution	10	41	30	16	2
Engineering	17	38	31	10	4

ence is an exception—some conference proceedings are very selective and very prestigious), which are more important than non-refereed articles. Nontechnical articles are less important than any of the above. Thus, the journal is used as a substitute for a direct measure of quality. Since there may be little difference in the time and energy required for publishing in prestigious journals, assistant professors are often advised to publish in these journals.

"Citation counts are one of the better indicators of the visibility and value of research" (Centra, 1993, p. 139). However, citation counts need to be normalized with respect to how active a field is and what the norms for citing are. In addition, self-citations probably should be removed. Unfortunately, many promotion and tenure committees look at the h-index without considering other factors. [To determine an h-index, first list the person's publications in order of the number of times they are cited with publication #1 having the most citations. Then count down until the number of publications counted equals the number of citations of the current paper. This is the h-index. Example A: Professor A has 40 papers and a total of 600 citations. The top paper (#1) has 150 citations, paper #10 has 14 citations, papers #11 and #12 have 11 citations and paper # 40 has 0 citations. Prof. A has an h-index of 11 (see problem 3 in Homework for another example).] Presentations at conferences and universities also count, but in a different way. Since most schools require recommendation letters from professors in the candidate's area to evaluate the candidate's research, assistant professors need to become acquainted with researchers in their area. It is easier for the professor to remember the candidate's research and to write a favorable letter if the professor knows the candidate. Excellent presentations, informal discussions at meetings, and networking help one to develop these personal connections. Networking does not replace the need to conduct good research, but networking (e.g., Misner, 2009) has become an important skill for faculty.

Who the candidate writes publications with is also scrutinized. Papers from the candidate's thesis are expected and count positively only if they are of exceptional quality or quantity. Since the thesis papers are expected but really do not count, it is important to finish them as soon as possible. This is one advantage of having a postdoctoral appointment. Under no circumstance should an assistant professor start a job before he or she has completed the requirements for a PhD. Once these papers have been completed, the candidate needs to sever the umbilical cord to the adviser. This is particularly important for professors who stay at the school where they earned their PhD. Besides papers from the thesis, the candidate should have a mix of papers written by her- or himself, with colleagues and with students. If all papers are written with colleagues, members of the promotion committees will wonder if the candidate is independent, and if all papers are solos, the question will be whether the candidate can work with others.

Support for research is necessary to continue doing quality research and to support graduate students. As is the case with publications, not all research support is counted equally. At many research universities grants from certain government agencies such as NSF, NIH, and NASA are more valued than other grants. External support is always more highly valued than internal university support. The most weight is given to grants with the candidate as the principal investigator (PI). Grants for which the candidate is a co-principal investigator or investigator also count but not as much. At undergraduate institutions research with undergraduates requires significantly less money, but external grants are always appreciated.

In the past, most research universities did not expect that assistant professors would have graduated PhD's within the six-year probationary period. Unfortunately, this expectation appears to have changed and in addition to having graduate students who are conducting research and writing papers with their advisor, assistant professors at many research universities are expected to have graduated at least one PhD. However, because of the six-year time constraint, assistant professors should not expect the research of their students to be sufficient for promotion and tenure.

Does engineering education research count? Most of the items used to analyze technical research are also in place for engineering education research. These include the availability of research grants, journals and conference proceedings with a reasonably well established pecking order, and a market for PhDs and postdocs who have done engineering education research. The National Science Foundation has grants for engineering education research and development. These grants are quite competitive and count toward promotion, but at many schools they count less than grants for technical research. Occasional education papers are often considered to be a "hobby" and may count very little. Depending on the institution, a serious effort at engineering education research may or may not be considered equal to technical research. A big part of the problem is that many senior professors have no idea how difficult it is to publish research in the top-ranked engineering education journal—*Journal of Engineering Education*. Publishing a review article is also a challenge but is not nearly as difficult as publishing a research paper. Professors interested in focusing on engineering education research need to determine in advance how promotion committees will look at this research. Surprisingly, many undergraduate institutions do not appear to value engineering education research.

A UK survey by Alpay and Verschoor (2014) found that STEM faculty believed that achievements with the most impact were novel technical research, technical research publications and reputation as a technical researcher, while those with the least impact were funding teaching activities and teaching publications. They observed a general desire of faculty to reduce teaching loads. When asked if technical research enhanced undergraduate teaching, 70.9% of the respondents agreed with 23.5 % choosing occasionally, 35.4% choosing often, and 18.0% choosing to a great extent. When asked if undergraduate education enhanced technical research, 45.0% of the respondents agreed with 25.7 % choosing occasionally, 13.5% choosing often, and 5.8% choosing to a great extent. Clearly, in the UK STEM faculty believe technical research is more important than teaching.

A final comment: Many full professors at research universities want to see a big, long-term research plan. What will the candidate be doing five and ten years from now? Develop a research plan to help guide your activities and to help impress the full professors.

Teaching counts, but not enough at most research universities. Of course, at institutions focused on teaching, teaching counts a lot. Since no one benefits from bad teaching, most departments want proof that teaching is at least adequate. Although the lack of a large number of student complaints may be sufficient proof, it is better to obtain positive proof by regularly obtaining student evaluations of the class. Unfortunately, at most research universities excellent teaching helps only in borderline cases. For example, if the promotion case looks to be a little early on the basis of research alone, excellent teaching may make the difference. Excellent teaching can be proven with teaching evaluations and teaching awards. In Chapter 16 we noted that teaching evaluations need to be used with care in promotion decisions. A uniform procedure for administration should be followed for distributing and collecting the forms. Items which ask for overall ratings should be used since they correlate more highly with student learning. Adjustments should be made for factors such as elective versus required courses, class size, time of day, or unpopularity of classes (such as laboratory courses). Finally, since different personalities do better in different types of courses, ratings should be collected for a variety of courses.

For promotion to associate professor and for receiving tenure, service has very little clout at most universities, although at four-year and community colleges service can be an important factor. Even at research universities one cannot totally ignore service, since failure to do one's share of committee work and other types of departmental service will be a negative factor. However, once a reasonable share has been done, more will not help. Professional society activities are also expected, but moderation is again the key. However, chairing sessions at national meetings is an excellent way to network with faculty in your interest areas. The fairly common practice of giving women and underrepresented minorities more committee and advising assignments is unfair if these activities do not count for promotion (Alexander-Snow and Johnson, 1999).

Ouellett (2010) notes that there has been a general broadening of the role of faculty, and rewards including promotion can now occur for activities in teaching and service. However, at least in engineering at research universities, these rewards usually occur after the professor has tenure. Once a professor has tenure, teaching and service do count at many institutions. Lee et al. (1997) were surprised by their survey result that faculty believed that service is rewarded more than teaching but less than research. Earlier, Sisson (1982) obtained the same result. Our observation based on anecdotal evidence, which is less reliable than surveys, is that service counts more for promotion to full professor than to associate professor, but we believe it is still third. However, service is probably more important than teaching for salary increases. A professor who does much of the departmental service is very much appreciated by the Head, and often the Head will reward this person with above average salary increases.

A final unwritten area is general conduct and personality. Promotion is not a case where "nice guys finish last." All things being equal, it is easier to promote a personable individual and easier not to promote a nasty person than vice versa. A talented nasty person will be promoted, but a mediocre nasty person probably will not. If you act in a collegial fashion, do your share willingly, get things done on time, and have a generally positive outlook on life, then you will benefit if your promotion is not clear-cut. Part of the tenure process involves the decision that the candidate fits in with the institution (Watson, 1991). This paragraph may seem unfair, but in industry the ability to get along and work with a team is more highly prized than in academia.

If all of this sounds to you like promotion and tenure committees nit-pick and search for any possible reason to doubt that the assistant professor should be promoted, then you have the right idea. However, despite all the nit-picking, the committees often make the right decision. We think that all the nit-picking occurs because committee members either want to impress other committee members or they want to justify voting no—a difficult decision for many professors.

Universities do change and the criteria for promotion and tenure change. Over the last 20 years publishing and research support have remained most important, but research universities have been able to redefine scholarship to some extent so that a broader range of activities is rewarded. This follows the main conclusion of the Carnegie report (Boyer, 1990). There has been a clear swing toward increasing the importance of teaching although the increase in weight given to teaching in promotion decisions was modest. As with the weather, it is often easier to talk about rewarding good teaching than to actually do anything about it. Some of the unhappiest people we know are professors who were hired to do one thing (teaching) and then had the university change and ask them to do something else (research). Professors need to watch the trends at their university.

17.3.4. Actions for Untenured Professors

Many professors want to argue with the values their university uses to set priorities for promotion and tenure. However, professors, particularly assistant professors, ignore the established reward system at their peril. Research universities do not punish professors for excellent teaching and for spending time with students. What universities punish professors for (by denying tenure or promotion) is not doing what the university asked for (research and money). To survive with your moral esteem intact, determine how to do both what you want and what the university wants. Previously (roughly before about the year 2000), there was enough time to do a good job on both teaching and research even if the new assistant professor needed on the job training to learn to write proposals, mentor graduate students, and teach. At many research universities expectations have increased so much that assistant professors need to start with as much preparation and experience in academic duties as possible. The actions that PhD students and postdocs who aspire to faculty positions should do are discussed in Appendix A immediately after this chapter.

What can you do as an untenured professor to increase the odds that you will be promoted and receive tenure? First, retain your sense of humor. It will help keep stress under control. Gray and Prow (2008) provide useful advice for new faculty along with a dose of humor. For example, hint #1: "Gray's Theorem of N + 2. The number of papers required for tenure is N + 2, where N is the number you published. Corollary: Gray's Theorem is independent of N." In a serious vein, they recommend serious networking with scholars in your discipline.

Find a teaching mentor (Felder, 1993; Felder et al., 2011 ; Williams et al., 2014) and a research mentor. The research mentor will probably be in your department, but the teaching mentor does not have to be in your department or even your college. If there is a formal mentoring program in your department or college, tap into it as soon as possible. New faculty who join volunteer formal mentoring programs are promoted faster than those who do not join (Wasburn and LaLopa, 2003). If you did not have a course on teaching as a graduate student, attend a teaching workshop that lasts at least three days— the ASEE National Effective Teaching Institute (NETI) is particularly effective (Felder et al., 2011). Proposal writing workshops are also very useful.

Find out as clearly as possible what the target is, especially since the requirements for promotion and tenure are a vaguely defined moving target. Thus, the opinions of several professors in addition to your mentors are important. Once the target has been identified, develop a plan (see Chapter 2) that focuses first on activities and priorities and then on appropriate schedules and to-do lists. List those things which count for promotion at your school and list those that you want to do. Plan to combine teaching and research by teaching classes in your research specialty. Unfortunately, women tend to be given fewer of these assignments (Creamer, 1998). Discuss with your chair the teaching assignments for the next several years and see if you can get commitments to teach an elective course and to teach courses several times in a row to reduce your preparation time.

Develop a tentative schedule for doing and publishing technical research (if you want educational research to count as research for P&T obtain a signed agreement from your dean). This schedule needs to include plans for writing proposals, visiting funding agencies, training new graduate students, doing research, going to meetings, networking, writing papers, and so forth. Discuss the plan with your research mentor. Since plans like these are usually overly optimistic, plan to get more done than will be needed to secure your promotion. Then if some of the plans are delayed, you will still have done enough.

Your plans should be developed for the entire probationary period at a sustainable pace. If you can do some research that will come to fruition quickly and some that will take more time to mature, you will have a steady stream of papers coming out. Since this is typically six-year period, you need to include time to relax. Even if family and other obligations would allow you to work more, work at most six days per week except in rare emergencies. Schedule an extra day to relax by flying to meetings on a Saturday. Schedule a week of vacation every year. In the long run these breaks will increase your efficiency, and you will get more done.

Keep a running record of things that you do to ensure that all pertinent information is included in the curriculum vita. This is important in order to avoid selling youself short in the promotion and tenure document. For instance, if you give three or four seminars every year at different universities, at the end of five years you will have accumulated between fifteen and twenty visits. If these are not written down, it is very easy to forget one or more of them. Keep a running curriculum vitae in a computer file. Get into the habit of recording things right after you have done them.

The world does not end when tenure is denied. Most engineers who are denied tenure go into industry (Watson, 1991). Their salary and job satisfaction are often higher than in academia. If teaching was a positive part of the academic experience, there are many part-time teaching opportunities available. Other faculty find another institution is a much better fit for their priorities.

17.4. FACULTY ENVIRONMENT

We will first discuss the faculty environment and explore the reason for the mixed messages from faculty: there may be widespread grumbling in the professorial ranks (Beaufait and Harris, 1989; Boyer, 1990; Duderstadt and Womack, 2003; Mooney, 1991), yet in many ways professors like their jobs (Boyer, 1990; Mooney, 1991). After considering the complaints, we will discuss what can be done to improve the environment for college professors. This discussion is continued in Section 17.5 on faculty development. Obviously, more money would help but is probably not forthcoming. In 2014, states in the US are slowly starving their state institutions while becoming more involved (some would say meddling) in the academics. Thus, the focus will be on what can be done with no or modest amounts of money.

Perhaps the best sources of information on the attitudes of faculty are the extensive faculty surveys done by the Carnegie Foundation for the Advancement of Teaching (Boyer, 1990) and by the Higher Education Research Institute at the University of California at Los Angeles. The signs of dissatisfaction were widespread in 1989 when the Carnegie study was conducted (Table 17-3). From the responses to question Q1 in Table 17-3, one can see that in 1989 the interests of engineering professors were split 50-50 between teaching and research, although teaching had more professors strongly interested in it. There was an obvious difference between professors' interests and the perceived requirements for tenure that are reported in Table 17-2. Assistant professors are usually hired from major research universities where they were socialized that research is the "supreme value" (Schwehn, 1993, p.5). Since assistant then associate professors are promoted based on their research ability, most members of promotion and tenure committees are successful researchers. Thus, the percentage of engineering professors more interested in teaching has probably decreased since 1989 (Wankat, 2013).

Unfortunately, the data pools for Boyer (1990) and the Higher Education Research Institute (2003, 2006) are different for Q1, but some comparisons can be made. The 2001–02 and 2004–05 public university data is probably closest to Boyer's all four year institution data. Comparing these sets of data, there appears to be a modest swing towards research.

Another source of dissatisfaction in 1989 was the perception that publication pressures reduce teaching quality (see Q2 in Table 17-3). More than half of the professors at research institutions and more than half of the engineering professors agreed with this statement. The

Table 17-3. Faculty Satisfaction

Answers Q1:	Research	Lean to research	Lean to teaching	Teaching	
Q1. Do your interests lie primarily in research or teaching?					
All 4 yr. Institutions	9	33	32	26	
Research Institution	18	48	24	9	
Engineering	7	43	23	27	
Public Univ. 01–02[a]	8.6	40.5	34.5	16.4	
Public Univ. 04–05[b]	7.9	40.8	33.4	17.9	
Responses to statements Q2 to Q8:	**Strongly agree**	**Agree with reservation**	**Neutral**	**Disagree with reservation**	**Strongly disagree**
Q2. The pressure to publish reduces the quality of teaching at my university.					
Research Institution	24	29	10	23	15
Engineering	24	29	13	19	15
Q3. During the past two or three years, financial support for work in my discipline has become harder to obtain.					
Research Institution	38	25	21	13	3
Engineering	29	23	34	12	2
Q4. I hardly ever get to give a piece of work the attention it deserves.					
Research Institution	13	33	12	30	13
Engineering	22	29	15	24	9
Q5. My job is the source of considerable personal strain.					
Research Institution	15	32	12	24	16
Engineering	16	33	18	20	12
Q6. If I had it to do over again, I would not become a college teacher.					
Research Institution	6	7	11	25	51
Engineering	8	5	11	21	54
Q7. I feel trapped in a profession with limited opportunity for advancement.					
Research Institution	5	9	10	19	56
Engineering	6	10	13	16	56
Q8. This is a poor time for any young person to begin an academic career.					
Research Institution	7	15	16	38	24
Engineering	11	17	15	32	25

Data from Boyer (1990), except where indicated otherwise: [a] Higher Education Research Institute (2003), [b] Higher Education Research Institute (2006); Answers are in percents

Table 17-3. (Cont.).

Responses to statements Q9 to Q11:	Very important	Fairly important	Fairly unimportant	Not at all important
Q9. Please indicate the degree to which your academic discipline is important to you.				
Research Institution	77	21	2	0
Engineering	75	23	2	0
Q10. Please indicate the degree to which your department is important to you.				
Research Institution	48	39	11	2
Engineering	52	42	6	0
Q11. Please indicate the degree to which your college or university is important to you.				
Research Institution	30	50	17	4
Engineering	41	43	16	1

interaction of teaching and research will be discussed in more detail later. There was also substantial agreement that it had become more difficult to obtain financial support (Q3, Table 17-3), and the situation appears to have become worse. For example, the percentage of NSF engineering education proposals funded in 2011 was approximately 12% for the Research Initiation Grants in Engineering Education (RIGEE) program, 19% for the Research/Educational Enhancement (REE) program, and 10–12% for the Transforming Undergraduate Education in Science (TUES) program (Wankat, 2013). In 2014, anecdotal evidence is that financial support for research is even more difficult to obtain than in the past. Professors also reported that they had difficulty putting sufficient time into any project (Q4, Table 17-3).

These sources of dissatisfaction add up to considerable strain on faculty (Q5, Table 17-3). Approximately half of faculty members report considerable strain. Duderstadt and Womack (2003) believed that all of these pressures had gotten worse. The Higher Education Research Institute survey (Mooney, 1991) reported that the following were major sources of stress:

1. Time pressures (reported by 83.5% of professors surveyed).
2. Lack of personal time (79.8%).
3. Teaching load (65%).
4. Managing household responsibilities (63.7%).
5. Committee work (57.5%).
6. Colleagues (54.2%).
7. Students (50.4%).
8. Research or publishing demands (50.4%).
9. Faculty meetings (49.6%).

The youngest faculty members reported considerably more strain than any other age group (Boyer, 1990). Clearly, there is a price to pay for trying to earn promotion and tenure. This is strongly supported by anecdotal evidence. Lee et al. (1997) point out that the discrepancy between what faculty thinks the university promotion and reward system should be and the faculty perceptions of the promotion and reward system will result in faculty dissatisfaction. Duderstadt and Womack (2003) believe that the major cause of faculty stress is rapid change in the roles of faculties and universities.

Table 17-4. Overall Satisfaction of Faculty With Their Career (De Angelo et al., 2009, p. 17)

	All ranks	Asst. Prof.	Assoc. Prof.	Full Prof.
Women	72.1%	71.7%	68.5%	74.3%
Men	76.6%	73.0%	73.2%	80.4%

Table 17-5. Results of Satisfaction Survey at RIT (Marchetti et al., 2012)

All things considered, how satisfied are you with your current position at RIT?			
females	57% satisfied	21% dissatisfied	Males more satisfied
males	64% satisfied	16% dissatisfied	$p < 0.05$
Profs. More satisfied than Asst. Prof.			$p < 0.01$
Non-STEM faculty more satisfied than STEM faculty			$p < 0.01$
With a scale of 1 = Very Dissatisfied and 5 = Very satisfied			
Average satisfaction by gender		Female	3.49
		Male	3.69
Average satisfaction by rank		Assistant	3.49
		Associate	3.49
		Full	3.90

Several questions in Table 17-3 show that in some ways college professors are satisfied with their jobs. Q6 shows that most professors would become college professors again despite everything they now know. In addition, Q7 shows that most professors do not feel trapped, and Q8 shows that most thought that 1989 was a good time to start an academic career. Clearly, there was something satisfying about being a professor when it is compared to the alternatives. Q9 to Q11 show that the academic discipline, department, and university were all important to professors but that their academic discipline had the highest level of allegiance.

Extensive national data for 2007–08 on faculty were reported by De Angelo et al. (2009). The overall satisfaction of faculty with their career is shown in Table 17-4. This data shows three trends that will continue in other data sets.

1. Male professors are more satisfied than female professors.
2. Full professors are most satisfied.
3. Associate professors are not more satisfied than assistant professors

Data collected in 2010 on the climate for male and female professors at Rochester Institute of Technology (RIT) is summarized in Table 17-5 (Marchetti et al., 2012). For both genders satisfaction with work/life balance was most strongly correlated with overall satisfaction. Males were more satisfied than females ($p < 0.05$). The mean score for work/life balance was significantly less for women ($p < 0.0001$), and the mean score for departmental climate was significantly less for women ($p < 0.01$). Composite score for value and influence was significantly less for African American, Latin American and Native American faculty ($p < 0.05$). Gender differences in satisfaction appeared to increase at the higher ranks, but were generally not significant because of small sample sizes.

What do these tables of data mean? There appear to be some major satisfactions to being a college professor. But there are some demotivating factors at work, some of which have increased in recent years. These factors include pressure on faculty, red tape, too many administrative responsibilities, too many courses to teach, inadequate staff support, lack of modern equipment, excessive workload, lack of influence, tenure requirements, lack of collegiality, a poor administration, gender and racial inequalities, and the low value placed on teaching (Beaufait and Harris, 1989; Boyer, 1990; Duderstadt and Womack, 2003; Marchetti et al., 2012; Mason et al., 2013). Interestingly, salary and fringe benefits are no longer the major problems they once were.

Gender and racial inequalities and bias, that are invisible to white males, are all too obvious to women and racial and ethnic minorities (Creamer, 1998; Marchetti et al., 2012; Mason et al., 2013; Trautner et al., 2002). For example, members of these groups are often asked to do additional duties that will not count in their promotion decisions, such as serve on committees, advise student groups, and present at recruiting fairs. They may be denied opportunities that will count in promotion, such as teaching upper division or graduate courses. The "white male way of acting" is often considered to be the norm. "Women's emotions and the manner in which they interact with others may be different from men. However, they do not differ in their intellectual abilities. Women are often accused of 'being too sensitive' or of 'taking things too personally'" (Trautner et al., 2002, p. 48). Women may be isolated, lack mentors, and, if they do research with a male professor, it is often assumed that the male professor is the lead in the research. Both women and underrepresented minorities complain about not being acknowledged as professors by students, other professors, staff and the police.

In their book *Do Babies Matter? Gender and Family in the Ivory Tower*, Mason et al. (2013) collect an overwhelming mass of data that illustrates the difficulties women face in academic careers. In 2000, women earned 49% of the PhDs awarded to US citizens in the US and currently women earn 51%. The median age of new male PhD recipients is 32 and of women is 33. Despite a number of years of equality in numbers of PhD degrees, many more men are hired as assistant professors than women. In engineering only 22% of PhD recipients are women. Earning a PhD in engineering tends to take less time than in humanities, but by time the almost mandatory post-doc has been completed new assistant professors in engineering are in their mid-30s. Waiting to start a family until after tenure becomes biologically risky for women. On the other hand, "Women who had children within five years of receiving their PhD were much less likely than men with early babies to acquire tenured professorships" (Mason et al., 2013, p. 3). And only one-third of the women who accept a tenure-track position before they have a baby ever become a mother. Women, whether they have children or not, receive tenure at a lower rate than men. Women with tenure are more likely to be single and more likely to be divorced than men with tenure. Women who earn tenure take longer than men to be promoted to full professor.

Retention of women and underrepresented minorities can be increased with a number of steps (Mason et al., 2013; Trautner et al., 2002). Workshops on gender and race/ethnicity can be remarkably effective at helping people become sensitive to these issues if they are strongly supported and attended by the upper administration. Faculty and staff need to realize that attendance is expected. A modest allocation from the dean's office can help support groups significantly. Family and child-bearing friendly policies that are enforced are necessary for everyone including post-docs and graduate students. Part-time positions with tenure that are convertible to full-time positions would provide needed flexibility for dealing with family responsibilities. Department heads need to make it clear that sexist or racist banter or "jokes" are unacceptable.

Collegiality is a caring about one's colleagues. It involves both informal and formal sharing of the load required for an excellent department. It involves cooperation instead of competition. In a collegial atmosphere everyone is glad when one professor wins an award since the whole department has won. Working and playing together leads to collegiality. In a collegial atmosphere everyone works within the system and tries to change things without being disruptive. Like good will, collegiality is a fragile resource easily lost and difficult to regain. Unfortunately, the competitive atmosphere of research universities causes collegiality to suffer (Astin, 1985). Malicious gossip, vendettas, paranoia and false accusations, temper tantrums, pettiness, and bickering all lead to a poisonous atmosphere. Many professors are lonely and interact with their colleagues only in the halls and in faculty meetings (Altman, 2004). One way to start to regain collegiality is to reinstitute Friday afternoon social hour with other faculty and graduate students. Another start is the development of ad hoc faculty groups to learn about new developments in mathematics, science, engineering, or education. Since young faculty members in particular complain about a lack of collegiality (Altman, 2004; Boice, 2000), an organized luncheon series to discuss teaching methods can be very helpful.

Boyer (1990) strongly urges universities to find new ways to define scholarship and to develop new methods for the evaluation of teaching. Universities that have followed these recommendations have probably reduced some of the demotivating stress and eased the strain, particularly on untenured faculty.

As noted in Q2 in Table 17-3, there is widespread belief that research can decrease the quality of a professor's teaching. At the same time there is widespread belief among administrators and researchers that research improves a professor's teaching. Neither belief is supported by the data on teaching evaluations. From reviews of the literature Feldman (1987), Prince et al. (2007), and Svinicki and McKeachie (2014) state that studies show little correlation between effective research and effective teaching. For practical purposes the correlation coefficient is zero. Ratz's (1975) study found no effect of research on teaching ratings of engineering professors. On the other hand, Kuriger (1978) found that the teaching ratings of engineering professors who did no research were considerably lower than those of professors who did research. The ratings of professors doing a moderate amount of research were slightly better than those of faculty with a large amount of research. If only elective courses were considered, then teachers doing a large amount of research did slightly better than those doing a moderate amount. Bresler's (1968) study of scientists and engineers at Tufts University agreed with Kuriger's study, except that Bresler found that professors who did extensive research received higher ratings in all courses. Since professors doing a lot of research often have significant clout in their departments, they may teach more than their share of elective courses. As noted in Chapter 16, students in elective courses give higher teacher ratings.

The disagreement between studies is an indication that the relationship between teaching and research on the level of the individual professor is complex. Murray et al. (1990) found that few teachers are either good or poor in all courses. Professors who are ambitious, competent, hardworking, and confident tend to receive high student ratings in methodology courses which are very work-oriented. These same personality traits are highly correlated with research productivity. Thus, for this one type of course one might expect a correlation between student ratings and research. However, correlation does not imply causation. In addition, the link between engineering research and the teaching of undergraduates is rather weak (Prince et al., 2007). Ideally, research or other scholarly activity reinforces teaching and both the teaching and the research improve. In engineering this is most likely to happen in elective courses since the professor has more freedom to discuss research. The advantages of doing research include developing faculty who are vital and enthusiastic, and the faculty in some sense remain learners themselves. However, there are other methods such as writing review papers that are probably just as effective if not more so (Centra, 1993).

Duderstadt and Womack (2003) imply that the pressure to do research, obtain funding, and publish has become worse, and that research interferes more with teaching than it did when the previously listed studies were done. The widespread belief that research interferes with teaching probably also comes from observation that on the university level research does weaken teaching (Astin, 1993). Research harms teaching if fewer faculty are teaching, the students are neglected, curriculum development is neglected, promotion depends only on research, university expenditures have shifted from instruction to research, or the uncertainty of being on "soft" money lowers faculty morale (Duderstadt and Womack, 2003). Fairweather (1999) estimated that faculty at research universities spend about 40% of their time teaching while at other institutions the percentage can be up to 67%. He found that it is difficult for professors to be above average in both teaching and research. However, universities routinely require a balance of research and teaching for each individual faculty member.

Enrollment and the supply of PhDs interested in becoming professors are cyclical. In 1992 an expected shortage of engineering teachers was a major concern. In 2014 the economy is still recovering from a recession, jobs in industry remain tight, and the supply of well qualified candidates to become engineering professors is greater than the demand.

A more diverse faculty would better match the more diverse pool of students. One could increase the pool by increasing the number of women and underrepresented minority BS engineers and by increasing the percentage of women and underrepresented minorities that go on to graduate school. This requires action from grade school through high school up to the undergraduate years. We can encourage more students to go to graduate school by stopping the current "burnout process," explaining the advantages of graduate school, increasing the stipend, providing teaching (Newton and Scholz, 1987) and research opportunities to undergraduates, pointing out the long-term economic return of graduate school (Kauffman, 1985), developing one-day workshops for undergraduates on graduate education (Blackmond, 1986), and selling students early on the joys of being a professor (Landis, 1989).

Another solution is to increase the percentage of underrepresented minority and women PhD engineers who become professors. Since salaries are competitive, other aspects of a professor's job need to be made more appealing. Innovative plans to lessen the sting of the probationary period for tenure may help. Careful analysis of the loads on different professors and efforts to give credit for additional activities asked of women and underrepresented minorities would help even the playing field. Innovative maternity and paternity leaves and plans to handle "the two-career problem" could attract well-qualified engineers into teaching. Candidates' choices of schools are heavily influenced by the reputation of the school (Matier, 1991). Other important factors over which the department has more direct control are teaching and research loads, teaching assignments, research opportunities, congeniality of associates, and rapport with departmental leaders.

Schools could also change the definition of "qualified." Aren't engineers with many years of industrial design experience qualified—probably more qualified—to teach design, laboratory, and possibly other courses than professors with no industrial experience? Some innovative institutions have developed Professor of Practice positions that allow them to hire experienced engineers at the right level without typical tenure and publication concerns. Could more use be made of "loan" engineers or engineers from industry on sabbatical? Our experience is that professors of practice and engineers on loan are usually very interested in students and teaching.

17.5. FACULTY DEVELOPMENT

Faculty development is needed because most graduate schools have not prepared PhD graduates for most of the duties they will perform as faculty members (Altman, 2004; Boice 2000; Brent et al., 2006; Reis, 1997; Wankat, 2002). Since the real quality of a university is not the facilities but the faculty and staff, universities need to make a long-term commitment to faculty development or they will risk having older, tenured faculty members who are both obsolete and burned out. It is essential that engineering faculty remain current with technological advances and industrial practice. One argument in favor of having engineering faculty do research is that research keeps them current. This is true, but often only in the professor's narrow specialty. Only very large departments can afford the luxury of having professors teach only in their special area. Most professors teach some courses that are not their specialty, but if they do not make an effort to stay current, the course will soon become somewhat stale. For teaching undergraduate courses, other methods for staying current, such as writing a textbook, consulting, writing review papers, and attending workshops, may be more effective than research.

Another reason for faculty development is that professors need to continually update their knowledge and skills as their roles change during their careers (O'Meara et al., 2008). The first three years are spent learning how to teach and starting on research. During this period new professors usually receive less help and mentoring than they want (Boice, 2000). For the second two or three years, assistant professors are very concerned about tenure and may explore alternatives should tenure be denied. Associate professors enjoy the recent promotion and tenure and become more involved in their institution. However, they may go through a "sophomore slump" since they are no longer receiving the attention and help that assistant professors receive. Full professors often go through a transition period or midlife crisis (Levinson and Levinson, 1996; Levinson et al., 1978). They may feel less enthusiasm for teaching and research and may suffer declines in student ratings and research productivity. In general terms, these professors must choose between stagnation and diversification. As retirement nears, the professor may start to withdraw gradually, possibly become more "mellow," and be very satisfied with service to the department and the profession. Professors need encouragement and help to be most effective in each of these stages.

Faculty development can be accomplished by the individual faculty member, but it is helpful if the department chair or dean provides encouragement in the form of modest financial support. Unfortunately, funding for faculty development is often the first item axed when money becomes tight (Altman, 2004). Growth or creativity contracts, in which the professor lists what will be done over a three to five-year period, are useful (Boyer, 1990; Simpson and Oggel, 1984). The advantage of a growth contract agreed-to by the chair and the dean is that the professor knows that successful completion will be recognized and rewarded. Otherwise, a professor embarking on a new path may find his or her efforts ignored. The growth contract recognizes that universities need faculty with interest and strength in a variety of areas, not just research.

Mentoring is another type of faculty development that can be advantageous for both new and experienced faculty. New faculty with mentors often get off to a much faster start in teaching and research (Boice, 2000). Those who receive role-specific modeling in teaching or research receive higher teaching ratings or are more productive in research. However, since people prefer mentors of the same gender, women are at a disadvantage in engineering. Women faculty get less faculty support than men but need more (Creamer, 1998; Gibbons, 1992). Experienced faculty who serve as mentors often feel that their mentoring is an opportunity to give back to the profession and may feel joy when their mentee succeeds (Veslind, 2001).

An obvious area for faculty growth is in teaching (Felder et al., 2011; McCrickerd, 2012; Wankat, 2002). Many professors are acquainted only with a non-interactive lecture style of teaching. Better teachers know instinctively what works, but usually do not know why and cannot explain how someone else can improve. For good teachers a very modest amount of study can have a major impact on their understanding of the teaching process, since they already have a rudimentary knowledge structure and are usually motivated to do better. However, major changes such as switching from lectures to active learning usually require support. Support is very helpful in overcoming fear, a major reason professors do not innovate more (McCrickerd, 2012). Poor teachers need to attend a teaching workshop (see Chapter 1). Then they need to experiment, receive feedback and encouragement, and try again. Of course, poor teachers must also have the motivation to improve. Boice (2000) found that new faculty wanted more help with teaching, and he observed that formal teaching development programs worked if new faculty enrolled in them.

In engineering, *ASEE Prism* is the most accessible source of teaching information on a monthly basis. The annual meeting of ASEE and the Frontiers in Education Conference cosponsored by ASEE and IEEE are good choices for workshops, symposia, and personal contact. Most universities have in-house teaching improvement programs, which can be useful for the knowledge and skills learned, and for the opportunity to meet other professors who are vitally interested in teaching. There may also be for-credit courses with titles such as "Educational Psychology for College Teachers."

Even if there are no courses, good teachers can be talked to and observed. One possibility is to work with a mentor (Felder, 1993; Gibbons, 1992), either on campus or while on sabbatical. A word of caution when you observe any professor: Many teachers are good teachers because they have major strengths in the second dimension of good teaching—rapport. The performance (lecture) ability of these professors may just be adequate, but the students respond to the rapport. Thus you must watch much more than just lectures. A formal mentoring program that assigns new professors to teach recitation sections and expects them to attend lectures is also useful. It involves an assistant professor closely with an experienced teacher and encourages informal discussions on teaching methods. In addition, since it is a rare professor who does not prepare for class when he or she knows a colleague will be present, the lectures will be well done.

Another approach is to become a student again and do all the work required to earn a grade (Culver, 2014; Wankat, 2003). As a student, professors will remember what it is like to learn new material from someone who knows more than they do, and the importance of encouragement will become very clear. Students also are users of the technology, which is very different than assigning students to use that technology, and as a student the professor will experience being dependent on the technology to succeed (Culver, 2014). Finally, while acting as a student faculty can learn more about student culture and probe into what students consider to be cheating.

Once you see, read, or hear about something you think will work for you, try it on a small scale. Students usually interpret small-scale changes and experiments as non-threatening, and they respond favorably. Large-scale changes in teaching are often seen by students as threatening (see Section 7.12).

A second major problem teachers have is content boredom. This is somewhat ironic since many professors are professors because they love the discipline, but anyone can become bored with teaching the same material semester after semester. Professors who teach because they love students are much less likely to suffer from boredom since the students change every semester. There are several obvious solutions when content boredom sets in, but they require extra work.

- Teach a new course.
- Team-teach, particularly a multidisciplinary course.
- Teach outside your discipline. Examples include teaching mathematics or physics or another area of engineering.
- Write a textbook.
- Develop courseware.
- Teach the same content with a radically different teaching method.

The university can help a faculty member develop skill in teaching. Paying for trips to ASEE meetings sends a not-so-subtle message that these meetings are as important as technical society meetings. Modest engineering-wide grants awarded competitively can help professors develop innovative teaching methods. Sabbaticals can be granted for teaching as well as for research reasons. Departments can organize mentoring programs, luncheons to discuss teaching, workshops and seminars. Teaching awards are nice but are most effective if made as a salary increase so that faculty benefit from them year after year.

Faculty members also need to consider development in research. New faculty will benefit from mentoring in being a research advisor. Research in the same area year after year can also become routine. To get past the routine and develop new ideas, a professor can start a totally new research area, though this is very time-consuming and is often easiest to do while on sabbatical. Perhaps one can ease into a new area by joining an interdisciplinary research team. Somewhat less drastic steps to invigorate a research program include going to different research conferences, auditing a graduate-level course in a new area, writing a critical review or research monograph, serving as an NSF program director on a rotating assignment, and integrating research and teaching by teaching a graduate-level seminar.

Faculty may also want to have a long-term development plan in engineering practice. For young faculty with no, or very little, practical engineering experience, summer jobs in industry can be helpful. Since the common wisdom is that this should not be done until tenure has been obtained, this is another case where tenure skews the educational system. Industrial sabbaticals can be useful, particularly in research areas where industry is at the forefront.

Consulting is also helpful, although the contact is usually too short to get a complete industrial flavor. To a lesser extent, working with other engineers through professional societies can be useful.

Finally, some professors may want to include service or administration in their development plans. One of the duties of faculty is to do their fair share in faculty governance (see Section 17.6). The faculty member may decide to do this by becoming involved in the university senate, the faculty union, the American Association of University Professors (AAUP), or heavy university committee duties. An alternative is administrative duties such as assistant department chair, department chair, or assistant dean (Greene and Van Kuren, 1995; Buller, 2012; Chu, 2012). A few universities actually train professors for these positions, but in the absence of a formal training program the professor can talk to professors who have held these positions in the past, read a few books, and perhaps find a suitable workshop.

A fully functioning department needs faculty who are interested in all areas of research, teaching, engineering practice, service, and administration. Felder (1994) calls this "the myth of the superhuman professor." Very few professors can be good in all areas simultaneously. Departments need professors who specialize in one or two areas. The current problem and challenge for the future is that research receives many more rewards than the others. A department can find itself with few professors interested in students, service, engineering practice, or administration. The results can include student revolts, a breakdown in service and a lack of curriculum development, difficulty at accreditation time, and a lack of leadership. Balance is needed but is difficult to maintain for long periods.

17.6. PROFESSIONAL ETHICS

The privileges of academic freedom, the latitude given to professors to choose research areas, and the security of tenure must be balanced with self-policed ethical behavior. Engineering professors have fewer constraints than their industrial counterparts and fewer external agencies watching their behavior than medical doctors or lawyers, so ethical behavior must be self-directed. Since ethical behavior must come from within, it is useful to study codes of ethics and to reflect on the applications of these codes. Henninger (1991) has a useful list of older references on academic ethics.

Some behavior, upon reflection, will clearly be seen as unethical. Other behavior falls into grey areas where it is arguable whether it is ethical or not. The professor may decide to avoid this behavior so that there is no question of impropriety. Alternatively, she or he may decide that the behavior is ethical, but to avoid the appearance of unethical behavior will inform the proper administrative authorities in advance. An example of a grey area involves a professor who commercializes the results of university research by starting a high-technology company. Since large amounts of money may be involved, some people will question the ethics of almost any arrangement.

A general code of ethics for engineers was introduced and discussed in Table 12-1. Naturally, this code applies to engineering professors as well as other engineers. The ramifications of any ethical code for an individual are often not clear until particular cases are discussed in detail. For example, does teaching when one is not a competent teacher violate Canon 2 ("Engineers shall perform services only in areas of their competence.")?

Table 17-6. Summary of AAUP Statement on Professional Ethics (AAUP, 2009)

The professor recognizes special responsibilities:

1. Seek and state truth in **subject** as he or she sees it. Intellectual honesty must be practiced. Other interests must never seriously interfere with freedom of inquiry.
2. Encourage **students** in the pursuit of learning. The professor will respect students, avoid exploiting students and honestly evaluate students.
3. Respect **colleagues** and defend their right of free inquiry. Do not discriminate against or harass colleagues. Acknowledge academic debts and accept faculty responsibility for institutional governance.
4. Determine amount and character of outside work with due regard to paramount responsibility within **institution** to be an effective teacher and scholar. Observe the institution's regulations as long as academic freedom is preserved. Give due notice of intent to leave.
5. As a **citizen** speak as an individual bound by the rights and obligations of a citizen. When speaking as a private citizen, avoid creating impression that the institution is represented.

The engineers' code of ethics was not written with the requirements of engineering professors in mind. The professorial aspects of the engineering professor's position are more closely related to the statement of professional ethics made by the AAUP summarized in Table 17-6 (AAUP, 2014). Engineering professors should adhere to both the engineering code of ethics and to the AAUP statement.

There are many ramifications of the AAUP statement of ethics. A complete enumeration is obviously impossible, and each case must be looked at individually. As an example, a few of the ramifications of each paragraph of the AAUP statement are delineated below.

1. Intellectual honesty obviously requires that research data be reported accurately. Falsification of data is unethical and illegal. Data which may be questionable can be reported, but all questions about the data must be fully discussed. Prior work must be acknowledged (see also item 3).
2. Exploitation of students includes the sexual exploitation of students. It is obviously unethical to exchange grades for sexual favors. Dating a student can inadvertently lead to ethical problems. It is better to wait until the person is a former student to begin a romantic relationship.

   A grey area of the ethical code involves the ethics of requiring students to purchase your textbook for a course. Authors are probably incapable of objectively determining that their book is not the best. One solution to this problem is to donate the royalty income from your students to the university.
3. Professors should not let personal differences cloud professional evaluations of the work of colleagues. Accepting a share of institutional governance requires that the professor do his or her fair share of committee duties. This may also mean that the professor should accept her or his turn as a member of the faculty senate or as the departmental chair.

4. Professors should observe the regulations of the institution as long as they do not compromise academic freedom. (The AAUP is very clear that academic freedom is a higher value than following the institution's regulations. Your institution probably sees this issue differently.) The professor may constructively criticize and try to change institutional regulations. However, we interpret this as meaning that trying to punish the institution would be unethical. Thus, a professor could ethically sue her or his university, but collecting punitive damages may well be unethical. If there is a conflict between outside work such as consulting and university duties, the university duties should be considered more important.
5. The professor has all the rights and obligations of a citizen. This can be interpreted to mean that outside her or his subject area the professor has no special privilege of academic freedom beyond those of every citizen.

Intellectual honesty and responsibility in research has become a topic of national importance, and the federal government through the US Department of Health and Human Services has established a number of policies. The Office of Research Integrity (ORI; http://ori.hhs.gov/) has a number of misconduct case studies and access to policies and regulations (all written in legal terms). "*Research misconduct* means fabrication, falsification, or plagiarism in proposing, performing, or reviewing research, or in reporting research results" (PHS, 2005, p. 28386). The ORI system depends on complainants (aka whistle blowers) making good faith charges of misconduct. This is both a strength since complainants often have access to the specialized knowledge necessary to realize that misconduct has occurred, but also a weakness since many researchers believe that whistle blowers are at risk of reprisals, even though reprisals are illegal.

The rules on monetary conflicts of interest have been tightened up and the minimum threshold for reporting has been reduced to $5,000 (NIH, 2011).

In actual practice professors have been very reluctant to accuse others formally of unethical scholarship, cheating on research results, or conflicts of interest. Such allegations can become very time-consuming, and it is widely perceived that whistle blowers often receive reprisals in some form. Clearly informing all students doing research of the ethical standards they are expected to follow can help eliminate the need to report others.

It is useful to insert a healthy note of skepticism. "In all of this, however, we must be on guard against any group which seeks recognition as spokesman for 'the profession,' and then seeks to impose its narrow definition of engineering ethics on us all" (Florman, 1976, p. 31).

17.7. GUIDEPOSTS FOR ENGINEERING EDUCATION (HOUGEN'S PRINCIPLES)

Olaf Hougen was one of the pioneers in chemical engineering education. In a memoriam, Bird (1986) shared the principles that Hougen used to guide the development of the Department of Chemical Engineering at the University of Wisconsin. We repeat these principles here since we believe that many of them will prove to be useful guiding principles for all engineering educators. The quotations are from Bird (1986).

1. *"The undergraduate program should be practical and conservative, whereas the graduate program should be imaginative and exploratory."* Undergraduate programs are

to a large extent training for industry and thus should prepare students for responsible engineering jobs. Graduate research should move boldly into new areas.

2. *"There should be a smooth flow of information from graduate research to graduate teaching to undergraduate teaching."* Since the graduate program moves boldly into new areas, it can serve as a testing ground for new material. Once this material has proved its worth, it should be moved into the undergraduate program. This implies that professors are involved in teaching at both the graduate and undergraduate levels, and in research.
3. *"If you can't find relevant problems to give the student, then you shouldn't be teaching the material to the students."* If there are no industrial problems currently or in the future which can be solved with a method, then that material should not be part of an engineering curriculum.
4. *"Use the best available information from the modern sciences."* Engineering should be based on scientific knowledge, and it should be up-to-date.
5. *"Well-founded and well-tested empiricisms are to be preferred over theories that have only a limited range of applicability."* Correlations should be scientifically based, and founded on extensive data. The data should be as comprehensive as possible since graduates will hold responsible industrial positions.
6. *"It is vital for engineers to know how to solve problems with limited and incomplete data."* Complete data is a luxury that is often unavailable. Students must be well-versed in estimation methods, particularly for physical properties.
7. *"Students are impressionable and learn quickly, and therefore a professor must make certain that he [or she] teaches in a responsible way."* Wild conjectures presented as fact or unethical behavior have no place in teaching.
8. *"It is important that the students have a good grounding in the basic fundamentals; there's nothing worse than a student who has a thin veneer of high-powered theory."* The basic ideas need to be stressed. Both undergraduate and graduate students with weak backgrounds should be encouraged to take remedial coursework.
9. *"We must always recognize that our students and our teaching assistants are young professionals."* The students and teaching assistants need the challenge and reward of helping to develop the engineering profession.
10. *"Faculty members have an obligation to assist colleagues in other institutions."* Visitors, particularly those from other countries, should be treated with respect and be provided with whatever information they need. In addition, faculty members have a responsibility to prepare excellent textbooks.
11. *"We have, as faculty members in a state-supported institution, a responsibility to serve the taxpayers by performing our job well."* Even though resources might be limited, the faculty needs to perform its assignments as well as possible.
12. *"Do not show emotions of bitterness or beratement or belittlement; ascribe the best motives to your associates; say nothing derogatory."* Florman (1987) points out that there is a fine line between useful argument and divisiveness. We must believe that all our associates have the best wishes of the university and the engineering discipline at heart. Hougen's is difficult advice to follow; however, if followed, it will lead to a collegial atmosphere within a department.

17.8. CHAPTER COMMENTS

Many of the topics in this chapter are only indirectly related to teaching in the classroom, yet they can have a major impact on how well a professor teaches. Tenure and promotion are issues of vital interest to potential faculty members. The other topics in this chapter seem to be of more interest to older faculty. Ethical concerns don't suddenly arise when one becomes a professor; courses at all levels should consider ethics (see Chapter 12). As is often the case, however, the topic is appended awkwardly to the end of a class, with the result that students don't appreciate its relevance. Graduate students are no different in this regard; however, they do find case studies to be of considerable interest.

HOMEWORK

1. Make a list of ten advantages of tenure. Make a counter list of ten disadvantages. Develop an alternative to tenure which would retain many of the advantages but have fewer disadvantages.
2. Develop a plan for how you will get promoted to associate professor.
3. The h-index was defined in Section 17.3.3, and the h-index of Prof. A was calculated. Example B: Professor B has 35 papers and 500 citations. The top paper (#1) has 45 citations, paper #16 has 18 citations, paper #17 has 15 citations, and paper # 35 has 0 citations. Prof. B has an h-index of 16. Does the h-index give a fair representation of which professor has had more impact through their research? Explain your reasoning.
4. Assume that you have just been appointed department chair. At your university the department chairs set raises within broad guidelines. However, the total dollar pool for raises is a fixed sum which averages to 4% of the total faculty salaries. Determine a scenario for how you will reward faculty. Consider the following faculty members:
    a. Professor R does research. He is nationally known and has a standing offer for a position from another university. His teaching ratings are abysmal.
    b. Professor T is a wonderful teacher, but he has not done research for ten years. He routinely alternates winning the best teacher award with Professor S.
    c. Professor E is a good teacher, does modest research, and serves the department whenever asked to do so.
    d. Professor A has a national reputation and is a member of the National Academy of Engineering. He is getting ready to retire in a year or two and is no longer doing research.
    e. Professor S is the chairman of the undergraduate curriculum committee, does all the departmental advising of undergraduates, is adviser to the student professional society, and is a good teacher. The students talk to him all the time, and he single-handedly prevented a revolt of the seniors in Prof. R's class. He is not doing research.
    f. Professor D has been an associate professor for twenty years. He is the outstanding racquetball player on the faculty, but you cannot think of anything else outstanding about him. He is a member of the organizing committee for a proposed faculty union.

   g. Professor N is a new assistant professor who has been with the department for one year. She seems to be off to a fast start in her career and already has one research grant.
5. Discuss the following scenarios. Is the professor's behavior ethical?
   a. Professor B is single. She has started dating one of the graduate students at your university. Consider three cases: 1) The graduate student is not in Prof. B's department, 2) The graduate student is in Prof. B's department, but she is not his adviser and he is not taking any courses from her, 3) Professor B is the graduate student's research adviser.
   b. Professor C is a highly sought-after consultant. He normally teaches Monday, Wednesday and Friday and is often gone on Tuesday or Thursday. He has the opportunity to make a great deal of money consulting for a new client, but would have to miss his Wednesday and Friday classes.
   c. Professor K is the department chair. He has allowed other professors in the department $1,000 for travel to professional meetings. So far this year Prof. K has spent $3,000 from departmental funds for travel to professional meetings himself.

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APPENDIX A

OBTAINING AN ACADEMIC POSITION

This appendix is focused on obtaining engineering faculty positions (National Academies, 2013; Reichert et al., 2002; Wankat and Oreovicz, 1983). The guides by Buller (2010), COSEPUP (1996), and Vick and Furlong (2008) are useful for more general analyses.

Post-doctoral positions before one applies for a faculty position in engineering have become increasingly important. Reichert et al. (2002) strongly recommend post-doc experience "no matter how vigorously one is being recruited. This is particularly true for women and underrepresented minority graduate students who are often recruited prematurely." Because of the ramping up of expectations for new faculty at research universities, you need to develop as much skill in academic duties during your post-doc as possible. The post-doc position should allow you to learn new research skills and to engage in activities such as mentoring and writing research proposals that you did not do as a graduate student. You also need to take the time to complete and submit all of the papers from your thesis. Unless you have had a course on pedagogy and a supervised teaching experience during your PhD, a post-doc position that will allow you to teach is a plus for all future academics and absolutely necessary for those who want to work at an undergraduate institution. At a minimum, by time you start as an assistant professors you should have taken a course in pedagogy or attended an extensive (3 days or longer) teaching workshop. The chance to work on engineering education research during your post-doc could be a plus. The National Academies book on the post-doc experience (COSEPUP, 2000) is a useful resource for students interested in post-doc positions.

To obtain an academic position, candidates go through a series of steps, with the foremost requirement being that they have something to sell: a solid graduate education that includes good research and often a post-doctoral position that extends their research and/or teaching capabilities. They should also know at least three professors well. This first step serves as the basis for the second step: building a resume.

The resume (called a Curriculum Vitae or CV in academe) should be carefully and professionally done. Include all significant professional activities, and for academic positions highlight research experiences (for research universities this is most important) and teaching (most important for undergraduate institutions). Include citations of papers that have been published, are in press (that is, have been accepted by an editor), have been submitted, and perhaps are in preparation. The latter category will be discounted by many examiners of your CV, but it probably doesn't hurt to include them. If you have had a substantial share in writing a proposal, include it also. List any TA duties, and if you did more than just grade papers, list the activities.

If you are looking for a position at an undergraduate institution you need to convince them that teaching is your calling. You can do that by including a number of the following activities during your graduate school and post-doc years:

- Take education courses.
- Earn a teaching certificate
- Win a teaching award as a TA
- Do a supervised internship in teaching
- Actually teach a course
- Do a teaching post-doc

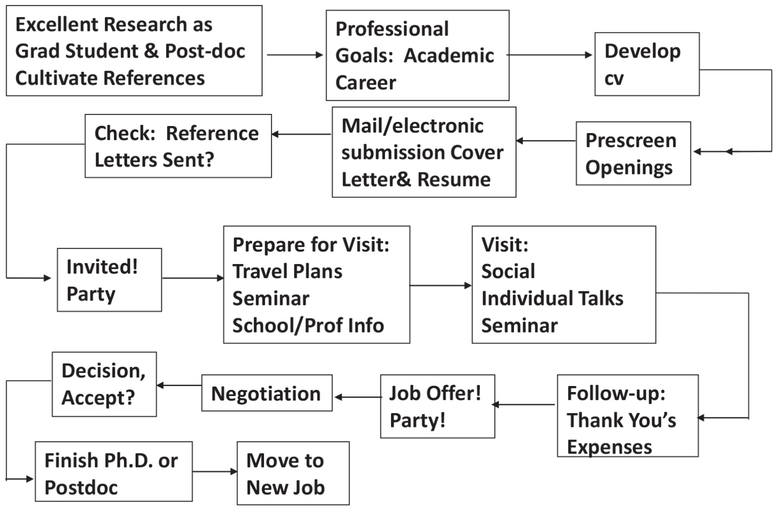
Include the names, addresses, e-mail addresses, and phone numbers of references on the CV. Since you will need good references from good people, you should have been getting to know professors professionally over the last three or four years. Include the references on your CV instead of stating that they are available on request since it reduces the barriers for prospective employers. When the CV is finished, ask two people to proofread it carefully. Many professors use the CV and your cover letter as an indication of how well you communicate in writing.

In some areas of engineering, the Department Chairs Organization collects the Curriculum Vitae of PhD candidates interested in academic positions. This can supplement your search, but do not assume that this resume collection will get you a job offer. Also, although your adviser can be very helpful, do not assume your adviser will get you a job (Morrissey, 2006).

The steps in obtaining an academic position are shown in Figure A-1 and outlined below.

1. While preparing your CV, develop a research plan and a teaching plan for the next five or so years. Many schools also request a teaching philosophy statement. These are separate documents which many schools want submitted at the same time as the CV. As for research, where do you want to be five years from now? Following up on PhD or postdoc research is fine, but be sure also to branch out from the research of your mentors. Research plans for undergraduate institutions should delineate how you will involve undergraduates in your research. For teaching, since you want to participate in teaching the undergraduate and graduate core courses plus electives, study the department's web page to determine what courses are offered. It is also appropriate to propose a new course that you are uniquely qualified to develop.
2. What equipment needs do you anticipate for getting started in your research? In many engineering fields it is now common to give new professors a start-up package. You need to determine three acceptable start-up packages. The first is a "blue-sky" package, which includes everything that you could profitably use in your research.

Figure A-1. Steps in the Academic Job Search



The second is a "middle-of-the road" package, which is sufficient to get you well started on research but leaves one or two major items of equipment for later acquisition. The third is an "absolute minimum" package, which is the minimum you can accept and still be able to do research in your area. These packages need to be developed thoughtfully. If you are applying to undergraduate institutions remember that research is a secondary function; thus, the equipment request needs to be more modest than the request for a major research university position.

3. Are there any major new experimental, numerical, or theoretical skills that will aid you in your research? If so, plan on how you will obtain these skills. Consider the appropriateness of a postdoctoral position (COSEPUP, 2000; Reichert et al., 2002). It can give you the opportunity to learn new research skills, work with a well-known professor, publish your PhD papers, write some more papers, and think deeply about research. In many engineering disciplines post-docs are expected by research universities. But! If not planned well, the postdoctoral position can become a holding pattern or a dead end.
4. While preparing your CV, prescreen openings. Every March the ASEE publishes the Engineering College Research and Graduate Study Directory, and in November the Undergraduate Programs in Engineering and Engineering Technology Directory. These two compendiums of data can be useful for comparing schools and for getting an idea of where to apply. Talk to several professors to obtain a qualitative feel for different departments. Be sure to get several opinions because individual biases can be strong. Now is also the appropriate time to become a reader of the academic openings sections of the appropriate journals in your area of engineering. In addition to the specialized journals, read the ads in ASEE Prism. If you are also interested in a nontraditional position such as general engineering, freshmen engineering, or an interdisciplinary engineering position, then check out the Chronicle of Higher Education job postings at https://chroniclevitae.com/jobs/position_types/1.

5. Next, decide on the schools to which you will apply. The prime source of these schools consists of those who have advertised. However, if you are interested in a particular university, send a CV even if you haven't seen an advertisement. Perhaps you missed it.
6. Prepare three generic cover letters: One for schools who have advertised a position close to your qualifications; and another for schools who have advertised a position that really doesn't fit your qualifications. Since many schools will bend qualifications for strong candidates, it pays to write to these schools. The third letter is for schools who have not advertised. Although cover letters and CV are usually sent as attachments to an e-mail, prepare the cover letter as a formal letter. Personalize these letters and all other correspondence by naming the school and the position you are applying for. The writing in the cover letter must be impeccable, or your CV may not receive the attention it deserves. Proofread all cover letters to be sure that you name the school the letter is going to and the correct position. Nothing is more damaging to a candidate than a letter that applies for the wrong position.

   If you can get your letters sent out a few months before a major professional society meeting, you can use the meeting to further your job search. Mention in your cover letter that you will be presenting a paper at the meeting (this obviously requires advance planning) and that you would be happy to meet with them at this meeting. Many departments use professional society meetings as a chance to screen candidates before inviting them for a campus visit. The department may send someone to listen to your presentation and may arrange an informal meeting with you. Come to this meeting prepared with extra copies of your research and teaching plans and CV. The professional society meeting can also provide an opportunity to meet with professors from schools you haven't yet applied to.
7. Once the letters and Curriculum Vitae have been sent, you sit and wait. Most schools will quickly send you a letter of acknowledgment, but this is likely to be the only thing done quickly. It is not unusual for departments to receive several hundred applications for a single position, and processing all of these applications takes time. Unless your obvious superstar status shines through, expect to receive many more negative responses than positive ones. For this reason, you need to apply to a relatively large number of schools.
8. Once you have at least one positive response, you can plan the interview trip. Arrange it at a time that is convenient for both you and the school. If you get several invitations to interview, put the schools you are most interested in third or fourth. The first and second interview trips will be learning experiences, and you will probably wish that you could do them over again. The third or fourth visit is also the best because by this time your seminar and your ability to answer questions have been polished. But don't take too many interview trips. They are tiring and time-consuming, and your interest and effectiveness will wane after some point. The key to the interview trip is preparation. Be prepared to discuss yours and others' research. Get a copy of the school's research report and study it. Find out what research the professors at the school are doing. You might even consider reading some of their recent articles. Be prepared to elaborate on your research plans for the upcoming years, and on how your research will expand and complement the department's current research.

9. Above all, be prepared for your seminar. Many schools use the seminar as a measure of how good your research is and how good a teacher you will be (ASEE, no date). Practice the seminar ahead of time and be sure it fits within the time guidelines. Start fairly slowly with a general introduction including the relevance of your research at a level that everyone in the audience can follow. Then lead up to the research results which will excite the experts. Practice answering both friendly and hostile questions by having your major professor and post-doc colleagues ask you questions. Avoid becoming defensive during the question period. Some of the questions may be purposefully hostile to see how you perform under pressure. If you don't know the answer to a question, say "I don't know. That is an interesting question and I'll find out the answer when I get back home." Tips on giving the seminar are given by Wankat and Oreovicz (1983) and ASEE (no date). At institutions that are heavily invested in teaching excellence you will probably be asked to also deliver a teaching demonstration that will be very different than a seminar.
10. Observe social amenities. During the visit do your best to shine both professionally and socially. If you are traveling across the country beware of jet lag. Relax and take a nap on the plane so that you will be fresh for dinner. During social occasions follow normal rules of etiquette—in particular, don't drink too much. If the evening starts to get too late, be assertive about your need to sleep. On the interview day be interested in the research of others and be enthusiastic about your own research.
11. Ask questions and determine the school's climate. Discuss teaching loads, start-up funds, office and laboratory space, travel money, and so forth with the department chair. Ask other faculty questions that will help you to determine the school's environment for teaching and research: How qualified are the undergraduate and the graduate students? Are the students generally satisfied with their education? Are secretarial and other services satisfactory, and are support staff generally treated with respect? Is the research space you will be assigned adequate, or does it require extensive remodeling? Are the assistant professors generally happy, and do they feel they have been fairly treated? Do the professors in the department work well together, or is there significant bickering and fighting? Since many people will not be bluntly honest, you will have to pay attention to numerous subtle cues to get a good picture of the department's health.
12. Use the return flight to begin your follow-up. Record your impressions of the department and note any questions that you forgot to ask but will ask if the department makes you a job offer. Make a to-do list of things to follow up on. Send a "thank you" letter to your host or hostess. If you have promised anyone further information, send it. Send in your receipts and expenses for the trip. Then, sit back and wait some more.
13. Assuming that you get a job offer, your ability to negotiate is greatest when you have received, but not yet accepted, a job offer. Although practically anything can be negotiated, a new assistant professor is most likely to want to negotiate the start-up package, teaching load and assignment, and salary. If the offered start-up package is less than your minimum package, then you might be better off refusing the offer. An alternative is to arrange a compromise, such as asking for the necessary amount of money but offering to spread it over several fiscal years. Of course, if you are being unreasonable, you may not find any schools that will provide sufficient funds. To avoid having this

occur, discuss your start-up needs with at least two professors at your university before starting the negotiation. Items involving salary, summer salary, and start-up funds should all be obtained in writing to avoid future misunderstanding.

14. To accept or not to accept? A key element in your decision should be your compatibility with your future colleagues. Are there a number of professors, including the department head, whom you can get along with? If not, carefully rethink accepting this offer regardless of how good the offer looks on paper.

It is not uncommon for graduate students to apply and be hired in a faculty position before doing a postdoc. Then after the postdoc they report to their new faculty position. This pattern changes the order of the steps, but does not change the steps in the process.

Most engineering departments have only one position open at a time. The department will want to know fairly quickly if you will accept the position. Murphy's Law holds here: The timing of offers never works out well. If you can, schedule all interview trips close to each other so that you can at least visit each school before you need to accept an offer. After one school gives you an offer, it is certainly ethical to visit other schools as long as you haven't decided to accept the first offer. An interview trip after you have an offer may well be your best since some of the pressure of finding a job has been removed. Tell the other schools about your deadline for making a decision. The school making the first offer probably will extend the time for decision if pressed but won't like to do so. Candidates who keep pushing the decision back, often eventually accept another offer. Once you have made a decision, accept the offer in writing, inform other schools of your decision, and then get back to work so that you can finish your thesis or post-doc research and report to work on time.

The procedure for professors who want to change jobs can be similar (Baldwin, 1990). A professor with a job may want to state on the resume that references will be supplied on request. In this way, the candidate can prescreen possible offers before letting the department chair know that other schools are interested. The professor already has a track record, and often interested universities will call him or her instead of the other way around. It is obviously flattering to be offered an interview trip that you haven't requested, but there may be good reasons to stay where you are. Every department has problems—at least you know what they are at your university. If the potential job offer is too good to turn down, then of course you will go and interview. Although there are arguments both for telling and not telling your current chair about the interview, in most cases it is probably preferable to tell the chair instead of having your chair hear about the interview trip through the grapevine.

Greene and van Kuren (1996) summarize searches from the point of view of the hiring department, and Stevens (1990) discusses a dean's view of hiring. Having an idea of how the process looks to these stakeholders can prove useful.

HOMEWORK

1. Convert your resume into a CV by focusing on academic aspects. Prepare research and teaching plans for the next five years plus a teaching philosophy statement as supplements to the CV.
2. Screen advertisements in appropriate journals for two or three months and develop a list of potential academic employers.

3. Write a cover letter to apply for an academic position.
4. Ask a faculty member in your field to review and provide feedback on your CV, list of potential employers, and cover letter.

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APPENDIX B

TEACHING ENGINEERING COURSE

The following outline, assignment list, and syllabus for a hypothetical Teaching Engineering course are provided as an example.

B1. SAMPLE COURSE OUTLINE

Aug.	22	M	Introduction. Course plan, Syllabus, Professional Behavior, Grading. Reading and other assignments are listed in Appendix B2.
	24	W	Attitude, Models of Teaching,
	29	M	Lecturing & content selection.
	31	W	Good Teaching & What Works (student selected) Version 1 Teaching Statement due.
Sept.	5	M	Labor Day—No class
	7	W	No class (make-up time for extra time on Sept. 14 & 26)
	12	M	Critique class visits due. Discussion of visits. Cooperative group learning.
	14	W	5:30–9:00, Student lectures* (10–12 minutes) + break activity (2–3 minutes)
	19	M	Discipline & classroom management.
	21	W	Academic Job Hunt panel (Student selected) Syllabus & Course Outline due
	26	M	5:30–9:00, Student lectures* (10–12 minutes) + break activity (2–3 minutes)
	28	W	Group discussions—Bloom, Piaget & Perry Objectives HW due

Oct.	3	M	Group discussions—Learning styles
	5	W	Long term co-op groups & PBL. Team assignments will be made.
	10	M	October break NO CLASS
	12	W	PSI/Mastery. ABET & assessment for ABET. Group selection teacher evaluation questions due. In class teams select topics for teaching. HW: Take Mastery quiz on ABET from Karen Heide in Forney 1060 on Oct. 13, 14, or 17. If needed, take 2nd quiz from Karen Heide on Oct. 18 or 19.
	17	M	No class (make-up time for extra time on Sept. 14 & 26)
	19	W	No class (make-up time for extra time on Sept. 14 & 26)
	24	M	Lecture on Testing.
	26	W	No class: 1st and 2nd groups consult with Prof. Wankat
	31	M	Assessment
Nov.	2	W	1st group teaching. Games and competitions
	7	M	2nd group teaching. How People Learn
	9	W	No class: 3rd and 4th groups consult with Prof. Wankat
	14	M	3rd group teaching. Teaching with Technology
	16	W	4th group teaching. Service Learning
	21	M	Promotion & Tenure—Student choice. Student written tests and solutions due
	23	W	NO CLASS. THANKSGIVING VACATION
	28	M	Grading revisited
	30	W	Test
Dec.	5	M	Discuss test & scoring. Working with TAs and graders.
	7	W	Course Evaluation. Panel: Experience of new faculty. 2nd draft teaching statement due
	12–16	M–Sat	FINALS. NO CLASS

*Student lecture topics: Piaget, Perry, Applications of Perry in Engineering, Bloom's taxonomy, Objectives, Maslow, Motivational interaction theory, Learning styles, Reliability and Validity of Learning styles inventory, Kolb's cycle, deep vs shallow learning, Moffatt's anthropological analysis, why students choose engineering.

B2. SAMPLE COURSE ASSIGNMENTS

Assignments are due at beginning of class period

Reading should be done before class starts.

TE = *Teaching Engineering* (1993), JEE = *Journal of Engineering Education*, EEP = *Effective, Efficient Professor* (these readings will be handed out in advance.)

Aug.	22	M	After class, look at 685_info_good_syllabus_.doc on Blackboard.
	24	W	TE section 1.2, EEP 79–81, 124–125 (EEP readings will be handed out). Students should start classroom visits on August 25th.
	29	M	TE chapter 6, EEP 65–79, Prince (2004), JEE, *93*(3), 223.
	31	W	TE, Chapt 1. EEP 40–46. Version 1 Teaching Statement due (see file in Blackboard).
Sept.	5	M	Labor Day—No class
	7	W	No class
	12	M	TE section 7.2. Prince (2004). Critique of class visit(s) due.
	14	W	On day not lecturing, read TE sections 4.1–4.4 and TE Chapter 14. Present Student lecture + break activity + HW question from lecture due.
	19	M	TE Chapter 12. Stevens, *College Teaching*, *44* (4), 140 (1996)—Full text available electronically through Purdue library.
	21	W	TE 348–352. Syllabus & Course Outline due. (The assignment is: “Prepare a syllabus including a daily course outline for an advanced graduate elective in your discipline that you would like to teach.”)
	26	M	On day not lecturing, read TE sections 4.1–4.4 and TE Chapter 14. Present Student lecture + break activity + HW question from lecture due.
	28	W	TE sections 4.1–4.4, TE Chapter 14. Objectives HW (on Blackboard) due
Oct.	3	M	TE Chapter 15.
	5	W	TE section 7.1 and 7.2. JEE, Smith et al., *94*(1) 87 (Jan. 2005); JEE, Litzinger et al., *94*(2) 215 (April 2005). Team assignments will be made in class.
	10	M	October break NO CLASS
	12	W	TE section 7.4. Read self-study-quest-eac.doc and ABET EAC Criteria 1-27-10.pdf Group selection teacher evaluation questions due. HW: Take Mastery quiz on ABET from secretary in Forney 1060 on Oct. 13, 14, or 17. If needed, take 2nd quiz from the secretary on Oct. 18 or 19.
	24	M	TE Sections 11-1 and 11-2. Stice, *Eng. Educ.*, p. 390 (Feb. 1979) (A copy will be provided)
	26	W	No class, 1st and 2nd groups consult with Prof. Wankat
	31	M	http://www.abet.org/assessment.shtml click on Assessment rubrics and on Assessment methods. Look at the various articles

			on rubrics, direct and indirect assessment methods. For a more thorough analysis beyond that required by ABET: JEE, Olds et al., *94*(1), 13 (Jan. 2005).
Nov.	2	W	First group teaching
	7	M	Second group teaching
	9	W	No class, third & fourth groups consult with Prof. Wankat
	14	M	Third group teaching
	16	W	Fourth group teaching
	21	M	TBA—Student choice
			Student written tests & solutions due
	23	W	NO CLASS. THANKSGIVING VACATION
	28	M	TE Section 11.5. EEP pp. 88-90.
	30	W	Be prepared for Test
Dec.	5	M	TE 14–16, 195, 221–223. EEP 193–196.
	7	W	Do Course Evaluation in class. 2nd draft teaching statement due
Dec.	12–16	M–Sat	FINALS. NO CLASS

Starting resources for team teaching topics:

All groups: Prince (2004).

A. How People Learn. NRC book by same name.
B. Service Learning. Contact Prof. Bill Oakes in EPICS. Jacoby, *Service Learning in Higher Education.*
C. Competitions. JEE, Wankat, *94*(3), 343 (July 2005).
D. Teaching through the Cycle. TE Sections 15.1 & 15.3. McCarthy, *The 4MAT System.*
E. Guided Design. TE 176-178. Wales and Stager, *Guided Engineering Design*
F. Evaluation of Teaching. TE Chapter 16. Centra *Reflective Faculty Evaluation*
G. Technology in Teaching.
H. Increasing Diversity in Engineering. Chubin et al, JEE, *94* (1), 73 (Jan. 2005).
I. Teaching By or For Disabilities.
J. Attitude. Parker Palmer, *The Courage To Teach.*

B3. SAMPLE COURSE SYLLABUS

CHE 685 SYLLABUS PURDUE UNIVERSITY
EDUCATIONAL METHODS IN ENGINEERING
Dates are Tentative and May be Changed

Prof. Phil Wankat (ARMS 1215, Phone 67531), e-mail [wankat@purdue.edu]

CLASS HOURS: M, W, FRNY 1043, 5:30–6:45 PM

Prerequisites. Admitted into a PhD program in Engineering or other technical discipline (Finished with MS or MS-bypass), or consent of instructor.

Auditing. Postdocs and professors are encouraged to audit the course. If unable to register for the course, graduate students will be allowed to audit. Auditors will be encouraged to participate in discussions and to do homework; however, they will not have an opportunity to participate in the presentations and teaching exercises. Auditing is a privilege not a right—disruptive auditors will be asked to stop attending the course.

Office Hours. Appointment is best although you can try drop-in. Use e-mail, or talk to me before or after class to make an appointment.

Goals. The broad goals of ChE 685 are:

1. Help prepare you for becoming a professor. Schedule an individual meeting with Professor Wankat if you want to discuss your career goals.
2. Help prepare you for college teaching.
3. Expand your horizons about teaching.
4. Make you *think* about teaching.
5. Provide a small amount of practice.

Textbook. P. C. Wankat and F. S. Oreovicz, *Teaching Engineering*, McGraw-Hill, New York, 1993. Available free as pdf files.

Additional Readings.

- P. C. Wankat, *The Effective, Efficient Professor,* Allyn & Bacon, Boston, 2002.
- *Journal of Engineering Education*, available as electronic journal from Purdue Libraries
- Other materials as assigned during the semester.

Content Structure. The course is organized into two major parts:

I. *Teaching*: Methods and procedures on how to improve teaching. This includes objectives, syllabus, teaching methods, educational technology, testing and so forth.
II. *Students*: Types, Development and Learning. This part covers psychological theories of student types, development, and learning theories and motivation.

The two parts are intermingled during the semester.

Professional Behavior. To be discussed in class. Graduate students are obviously expected to behave in a professional manner consistent with the Engineer's Code of Ethics (if you are not familiar with this code, look it up at http://www.nspe.org). This code includes "Being Honest," "Engineers shall build their professional reputations on the merits of their services," and "Engineers shall act in such a manner as to uphold and enhance the honor, integrity, and dignity of the engineering profession." Cheating, plagiarism, self-plagiarism, and copying are considered to be much more severe offenses for graduate students than for undergraduates. In class we will also consider items such as absences, late attendance, late assignments, students unprepared for discussion, cell phones, computer use during lecture, and disruptive behavior.

Presentations. Mini-lectures on September 14 and 26. Will be videotaped. Turn in your critique of your presentation one week later.

Participation. In class and in teams.

Team Assignments. Everyone will be assigned to a team that will:

1. Complete a non-lecture teaching team assignment (teaching will be for an entire class period) using active learning methods. Dates are Oct. 31, Nov. 2, 7, 9, 14, 16.

   Topics (each one A-I can be chosen by only one group—order of selection will be by lot): A. How People Learn. B. Service Learning. C. Competitions. D. Teaching through the Cycle. E. Guided Design. F. Evaluation of Teaching. G. Technology in Teaching. H. Increasing Diversity in Engineering. I. Teaching by or for disabilities. J. Group selected and approved by Prof. Wankat. *Topics will be selected in class on Oct. 24.* Teams need to decide in advance the order they want topics (like the football draft—your first choices may not be available by time your team picks). Teams will also turn in a sample homework assignment (it will be graded, but will not be used as class homework).

   NOTE: The material covered in the team presentations should be included in the student written tests and will be included on the course examination.
2. Select items for the teaching evaluation form together. Due Oct. 12.

If there is someone you do *not* want to be on a team with, give Prof. Wankat this information (written on a piece of paper with your name and the name(s) of those you do not want to work with) no later than October 3rd before class.

Other Assignments.

1. Various miscellaneous assignments such as: homework from lecture presentation (due day of lecture), homework assignment on objectives, which is due September 28th, mastery quiz on ABET October 13–17th with 2nd try on October 18 or 19th, first draft of teaching statement due Aug 31st, and select items for teaching evaluation form (team exercise; hand in on October 12th).
2. Short critique of classroom visits. One page minimum, two page maximum, double-spaced. Due September 12th.
3. Write test and solution key for CHE 685. Should be reasonable coverage of topics at different levels of taxonomy. You can share copies (paper or electronic) with your classmates *after* you turn your test in. Due November 21st.

4. Prepare a syllabus including a daily course outline for an advanced graduate elective in your discipline that you would like to teach. Note: this will help in firming up your teaching statement. Due September 21st.
5. Second draft of teaching statement. Due December 7th. [First draft (will be commented on, but no grade) is due August 31st.]
6. Other?
   a. Could be theory paper: "The implications and use of ______________ in engineering education." Topic: Piaget's Theory or Perry's Theory or Kolb.
   b. Or could be Teaching Statement for NSF Career Proposal.
   c. 3–4 pages, double-spaced, typed, 12 point Times New Roman with normal margins. Due date is negotiable.

Exam. Will be based entirely or mainly on questions from the exams written by the students. The correct answers to questions will be developed by the instructor. The test will include material from the student lecture presentations and material from the student teams' non-lecture teaching. Date is November 30th.

Grading. Must take course for grade (Pass-Not Pass will not be allowed). Although past performance is not a guarantee of future performance, students have earned more A's than B's in the past. More details on grading and % for different items will be discussed in class.

	%
Grading Scheme	
Examination score	20
(developed in class)	
Lecture Presentation	15
Critique of own presentation	
Team teaching presentation & sample HW	20
Peer rating	
Assignments	
Critique of Classroom Visits	5
Syllabus & Course Outline	5
Teaching Statement—2nd version	10
Test & Solution Writing	10
Participation & misc. assignments	15
HW from lecture presentation	
Objectives HW	
Mastery quiz on ABET	
	100 %
Extra Credit	
(e.g., Teaching part Career Proposal,	
Or Paper on use of theories)	5

NAME INDEX

SUBJECT INDEX