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
Learning Theories

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 stu-
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 mod-
els 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 pre-
ferred 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 pre-
fer 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 engineer-
ing 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 solu-
tion 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 integra-
tion 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 coeffi-
cient. 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 mechani-
cs and other areas. Field trips or at least professionally produced videos of plant sites help stu-
dents 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 edu-
cation systems. Reading in Western cultures is a visual representation of auditory processing
techniques. In contrast, Chinese ideograms are closer to visual processing, and Eastern edu-
cation 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 sup-
plemented 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>
<thead>
<tr>
<th>Dichotomy</th>
<th>Students</th>
<th>Faculty</th>
<th>Student-Faculty</th>
<th>Student-Lecture*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active vs. Reflective</td>
<td>64%</td>
<td>45%</td>
<td>Mismatch 51.4%</td>
<td>Mismatch 100%</td>
</tr>
<tr>
<td>Sensing vs. Intuitive</td>
<td>63%</td>
<td>41%</td>
<td>Mismatch 52.3%</td>
<td>Mismatch 52.3%</td>
</tr>
<tr>
<td>Visual vs. Verbal</td>
<td>82%</td>
<td>94%</td>
<td>Match 78.2%</td>
<td>Mismatch 82%</td>
</tr>
<tr>
<td>Sequential vs. Global</td>
<td>60%</td>
<td>44%</td>
<td>Mismatch 51.2%</td>
<td>Mismatch 51.2%</td>
</tr>
<tr>
<td></td>
<td>40%</td>
<td>56%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*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,
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
Learning Theories


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)

<table>
<thead>
<tr>
<th>*Diverger (1)</th>
<th>Assimilator (2)</th>
<th>Converger (3)</th>
<th>Accommodator (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motivation</td>
<td>Information and facts</td>
<td>Try it</td>
<td>Do it yourself</td>
</tr>
<tr>
<td>Reflective</td>
<td>Reflective Lecture</td>
<td>Active Homework problems</td>
<td>Active Self-selected project</td>
</tr>
<tr>
<td>“War” stories</td>
<td>Brainstorming</td>
<td>Laboratory Simulations</td>
<td>Design</td>
</tr>
<tr>
<td>Observations: Instructor or video demonstration</td>
<td>Field trips CAI</td>
<td>Open-ended problems</td>
<td></td>
</tr>
<tr>
<td>Field trips</td>
<td>“On street” Patterns</td>
<td>Problem solving</td>
<td>Field trips</td>
</tr>
<tr>
<td>“On street”</td>
<td>Logs Organizing</td>
<td>Short answer</td>
<td>Work experience</td>
</tr>
<tr>
<td>Journals</td>
<td>Analyzing Reports</td>
<td></td>
<td>Simulations</td>
</tr>
<tr>
<td>Role playing</td>
<td>Objective tests Demonstrations</td>
<td>Teach yourself</td>
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<tr>
<td>Discussion</td>
<td>Library Work Experiment</td>
<td>Teach others</td>
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</tr>
<tr>
<td>Questioning</td>
<td>Examples Tinker</td>
<td>Think tank</td>
<td></td>
</tr>
<tr>
<td>Visualization</td>
<td>Seminars Record</td>
<td>Make things work</td>
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</tr>
</tbody>
</table>

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).
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, *intrinsic 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 student’s 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.

REFERENCES


McCarthy, B. (1987). The 4MAT system: Teaching to learning styles with right/left mode techniques. Barrington, IL: EXCEL.


