CHAPTER 15

LEARNING THEORIES

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 which "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 and friction are introduced, and the knowledge structure has be reconstructed. Such a reconstruction may be difficult (this is discussed later), 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.

15.1. CONSTRUCTIVISM AND THE SCIENTIFIC LEARNING CYCLE

What makes students go through the agony of such reconstructing? The answer appears to be the disequilibrium caused by new data which cannot be explained by the old model, and the inability to solve required problems. Bodner (1986) notes that many students find mathematical arguments and lectures with little discussion insufficient reason to discard the pre-newtonian model. 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 these new data should be forcefully pointed out. The second step is the availability of 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 constructivistic 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 which is easy to recall from memory is aided if students are given objectives which 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 in physics 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. In the laboratory 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 which is 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. Or, in computer language, the focus is on output devices and not input devices. 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 noninteractive lecture, satisfies the conditions of the traditional theory, but not the conditions of the 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. Some professors allow students to consult key relation charts during tests. Since the preparation of such a chart is a useful exercise, this is an interesting alternative to open book tests.

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; Smith, 1987). 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 to remember (see Section 15.2.2). 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. See Figure 5-1 for an example of a concept map.

Constructivism can help to explain how individuals solve problems. Problem solving appears to require both a general problem-solving strategy and specific knowledge (Kurfiss, 1988; Pintrich, 1990). 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 to start reconstructing the knowledge structure to solve the problem. Without specific content knowledge the general procedures are insufficient. Thus, engineering professors need to teach content and procedures. Teaching problem solving is the topic of Chapter 5.

Piaget's ideas and constructivism have led to a theory of how to teach science which is known as 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 [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

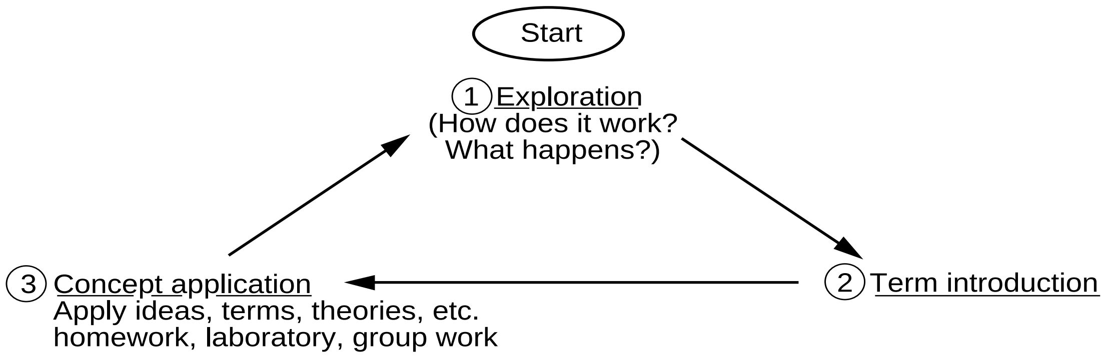

FIGURE 15-1 SCIENTIFIC LEARNING CYCLE

levels. There is considerable experimental evidence that the scientific learning cycle is more effective in teaching science than are the 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 to use these new terms to describe the patterns as completely as possible. The professor then fills in the missing parts of the pattern to give a complete scientific picture. This phase can be accomplished through lecture, readings, video, guided discussion, and so forth.

In the third phase, concept application, concept expansion, or idea expansion, students apply the new ideas, terms, and patterns to new examples. For instance, if the exploration phase involves development of a new physical law, then the law can be applied in new ways. This phase can involve homework, group discussions, or laboratory.

Although developed originally for use with laboratory manipulations in the exploration phase, the scientific learning cycle can be modified for other types of experiences. For example, the exploration phase can involve a computer simulation game which allows students to explore the simulated properties of some process or device. Alternatively, students can explore through video, slides, or even a lecture-question format. The key is to have students discover concepts on their own instead of being "spoon-fed."

The scientific learning cycle follows the ideas of constructivism. The exploration phase uses experiences (often concrete) to present data which cannot be explained by the students' existing knowledge structures. Students are encouraged to develop new knowledge structures by assimilation or accommodation, and the teacher ensures that this information is encoded with the correct terms. The concept application phase helps to organize the new knowledge structures.

The scientific learning cycle can easily be adapted to engineering education if appropriate laboratory equipment or computer simulation games are available. Adoption of the learning cycle to lecture-style classes is more problematic but is certainly possible. Demonstrations in front of an entire class can represent a concrete chance to explore, although with less freedom than with individual laboratory equipment. Exploration can also take place in lectures if the instructor describes phenomena and then has the students "experiment" by asking questions. The instructor has to be careful to allow them to discover concepts on their own. This approach may seem less efficient than the traditional lecture, but if efficiency is defined as student learning per amount of time, then the scientific learning cycle is more efficient.

15.2. 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.

15.2.1. Dichotomous Styles

Many investigators have described dichotomies in learning styles. The Meyers-Briggs scheme includes the sensing-intuition dichotomy, while Belenky et al. (1986) 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).

Information processing can be either deep or shallow (Claxton and Murrell, 1987; Schmeck, 1981). Deep processors learn the meaning and connections of ideas, whereas shallow processors tend to learn in terms of symbols and by memorization. For example, a deep processor learns the meaning of an equation and is able to use the equation if the symbols are changed. A shallow processor learns the equation in terms of symbols. If the meaning of symbols is changed, the shallow processor may have considerable difficulty in using the equation. Most students are capable of both types of processing. The professor, through homework and tests, exerts considerable control over which type they use. If the homework and tests emphasize rote learning, then shallow processing is reinforced. This is probably a good reason for not requiring the memorization of a large number of equations. Students in the concrete operational stage of development or on the dualistic levels of Perry's model may not be able to do deep processing, since deep processing skills appear fairly late in the developmental process.

Another learning style dichotomy involves deductive versus inductive learners (Felder and Silverman, 1988). 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. When students are seeing the material for the second time, deductive reasoning is a very effective presentation style. Since a preliminary knowledge structure exists in this case, they have something on which to build their deductions. The apparent success of deductive reasoning in these cases has seduced many professors into employing deductive reasoning at all times. Introductory textbooks 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. A deductive style may be advantageous for advanced textbooks where students are seeing the material for the second or third time. 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 learning represents another useful dichotomy for understanding the dynamics of teaching and learning (Claxton and Murrell, 1987; Robinson and Heinen, 1975). 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, and they often self-select into analytical fields such as engineering, mathematics, and science. Field-sensitive individuals are strongly influenced by authority figures and peer groups. They tend to be more people-oriented and are often good at working with others because they are aware of subtle messages. 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 some 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 individuals in engineering (see Chapter 11).

People appear to process information either serially (sequentially) 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 which 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 to be discussed 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 which is discussed in Section 15.3. Active experimenters want to do something with the information in the external world. For example, 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 noninteractive 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.

Whether these dichotomies are independent constructs appears to be doubtful. Claxton and Murrell (1987) report that Kirby (1979) hypothesized that there may be only two fundamental groups which he calls “splitter” and “lumper” types and which overlap with left-brain and right-brain analyses. The splitters include field-independents, serialists, abstract, separate-knowledge individuals, whereas the lumpers include field-sensitive, holistic, concrete, connected-knowledge individuals. If this is true, then the dichotomies are not independent, but each dichotomy adds to the picture of how people learn. However, individuals are complex and have the disturbing habit of not fitting into any theory.

15.2.2. Auditory, Kinesthetic, and Visual Modes

People 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 of the food and the table. Then you can 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 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; Murr, 1988; Waldron, 1986).

Kinesthetic learning includes taste, touch, smell, and feelings. Kinesthetic learning is important for chefs, athletes, therapists, artists, skilled craftspersons, 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 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. Smell can help tell if a process is operating correctly or incorrectly. 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.

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. This appears to be the preferred mode of learning for most people (Barbe and Milone, 1981) and was the preferred mode for engineering students (Anderson, 1991). The phrase, "A picture is worth a thousand words," is a common-sense way of saying that most people prefer visual learning. Visual information appears to be easier to understand and place into memory than words (Kiewra, 1987). Visual learning can be incorporated into engineering education in a variety of ways. Plotting equations to show their shape makes them much more real for many students. This can be done conveniently with calculators with plotting screens. Graphical solution methods are easier for many students to understand than solving equations analytically. Showing that the intersection of two curves is the simultaneous solution of two equations helps students understand what this means. Graphical solutions to more complex problems such as a McCabe-Thiele diagram in distillation or a Bode plot in control, help many students understand the solution procedure. Showing graphical integration procedures and comparing these to Simpson's rule or other integration procedures helps clarify for the student the meaning of the integration procedure. Correlations of data should be shown both in a figure with the scatter of data and as an equation with the correlation coefficient. Equipment sketches and diagrams should be insisted on for the solution of all problems. Computer-aided three-dimensional diagrams can help to clarify complex concepts in mechanics and other areas. Field trips or at least professionally produced videos of plant sites help students see the "real thing." For many students this one-time exposure to real equipment makes an entire semester of equations and problem solving much more understandable. Students in co-op programs also benefit from this aspect of visual education.

Auditory teaching methods are most commonly used in Western education systems. This includes lectures and print material. Reading in Western cultures is a visual representation of auditory processing techniques. In contrast, Chinese ideograms are closer to visual processing, and Eastern education has a more visual character (Murr, 1988). Writing words or equations on the blackboard is also a visual representation of an auditory method. Few people prefer to use auditory learning if given a choice; however, the Western educational system does not usually provide for a choice. Successful students have adjusted 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 the information. Stice (1987) reports on some early data from the Socony-Vacuum Oil Company which supports this contention. For reading alone, the learner's retention was 10 percent; for hearing alone, 26 percent; and for seeing, 30 percent. If the learner both saw and heard, retention was 50 percent; if the learner said something, retention was 70 percent; and if the learner said and did something, the retention was 90 percent. Thus, auditory styles of teaching should be heavily supplemented with visual and, to a lesser extent, kinesthetic learning opportunities. Opportunities for the student to speak, write, and solve problems should be incorporated in the course. With a little creativity this can often be done without major changes in the course format or coverage. Since visual learning is the preferred style for most students, it is also useful to consider if the entire course can be presented in a mainly visual style. This revision would probably require major changes in the course.

15.3. KOLB'S LEARNING CYCLE

Kolb (1984, 1985) developed a two-dimensional circular or three-dimensional spiral model of how people learn (see also Atkinson and Murrell, 1988; Claxton and Murrell, 1987; Felder and Silverman, 1988; McCarthy, 1987; Stice, 1987; Svinicki and Dixon, 1987). Kolb's model starts with two dichotomies which are considered to be orthogonal to each other. The first of these, active experimentation (AE) versus reflective observation (RO), was discussed briefly in Section 15.2.1. This dichotomy refers to how individuals prefer to transform experience into knowledge. Individuals who favor active experimentation like to get things done and see results. Reflective observers prefer to examine ideas from several angles and 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. Abstract conceptualizers prefer logical analysis, abstract thinking, and systematic planning. Individuals who favor concrete experience want specific experiences and personal involvement, particularly with people, and tend to be nonsystematic.

Kolb considers each of these four areas to be steps in learning. McCarthy (1987) modified and extended Kolb's model to apply it to teaching. The complete learning cycle shown in 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 to perceive the information that has now been changed by reflection. Next the learner processes the information actively and does something with it. 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 is a theory describing the steps required for complete learning. Unfortunately, students often take short-cuts and employ only one or two stages in the cycle, which results in significantly less learning. A study of the retention of knowledge showed 20 percent retention when only AC was used, 50 percent with RO and AC, 70 percent with CE, RO, and AC, and 90 percent when all four stages were employed (Stice, 1987). Most college education is geared to abstract conceptualization, but retention (hence long-term learning) is

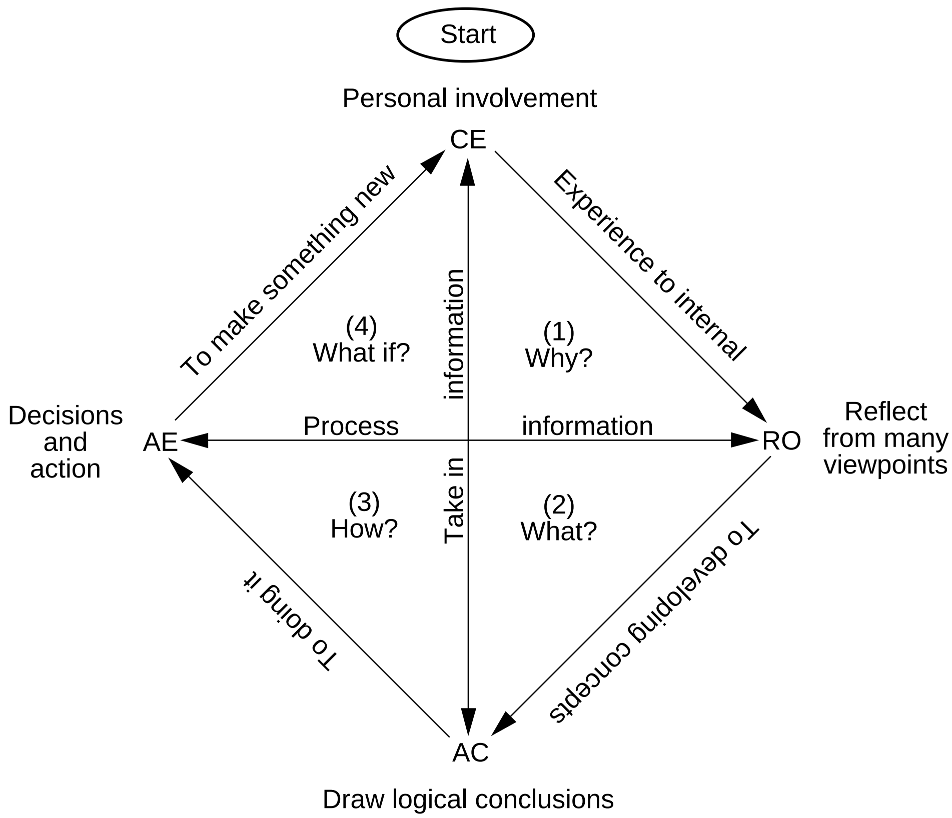

FIGURE 15-2 MODIFIED KOLB'S LEARNING CYCLE.
Learning styles: quadrant 1, divergers; quadrant 2, assimilators; quadrant 3, convergers; quadrant 4, accommodators.
Based on Kolb (1984), McCarthy (1987), Harb et al. (1991), and Svinicki and Dixon (1987).

enhanced by use of other stages in addition. Requiring more active involvement by students increases learning because additional stages in the learning cycle are used. Cooperative education and summer jobs aid learning 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). Stice (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).

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 Harb et al. (1991), Terry et al. (1991), and Todd (1991). We will discuss the modified and extended Kolb learning cycle or 4MAT system in more detail.

TABLE 15-1 TEACHING AND LEARNING ACTIVITIES (Harb et al., 1991; McCarthy, 1987; Svinicki and Dixon, 1987)

Diverger (1)	Assimilator (2)	Converger (3)	Accommodator (4)
Motivation	Information and facts	Try it	Do it themselves
"War" stories	Lecture	Homework problems	Self-select projects
Brainstorming	Reading	Laboratory	Design
Observations:	Instructor or	Simulations	Open-ended problems
Field trips	TV demonstration	CAI	Write problems
"On street"	Patterns	Problem solving	Field trips
Logs	Organizing	Short answer	Work experience
Journals	Analyzing	Reports	Simulations
Role playing	Objective tests	Demonstrations	Teach yourself
Discussion	Library Work	Experiment	Teach someone else
Questioning	Problem-solving examples	Tinker	Think tank
Visualization	Seminars	Record	
		Make things work	

This 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 which 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 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 activities. Possible teaching and learning activities are listed in Table 15-1.

In the second quadrant 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, and activities are listed in Table 15-1.

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. Activities are listed in Table 15-1.

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 very different understanding of the knowledge. In this 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. Other activities are listed in Table 15-1.

The usual college education uses what McCarthy (1987) calls a "pendulum style" of teaching. That is, it oscillates between quadrants 2 and 3. This style never goes around the entire cycle. Thus students are seldom motivated and seldom have the opportunity to do it themselves unless they have co-op or summer jobs. The pendulum style reduces retention and, as we shall see shortly, does not satisfy the favorite learning style of many students.

Kolb also developed a theory of learning styles (Kolb, 1984, 1985; McCarthy, 1987). A short psychological test which provides numerical scores for the grid is available (Kolb, 1985). The four styles are illustrated in Figure 15-2. Convergers prefer abstract conceptualization (AC) and active experimentation (AE) (quadrant 3). 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. Many engineers, technologists, computer scientists, and physical scientists are convergers. The favorite learning style of convergers is in quadrant 3 where they can do experiments and design equipment. If too convergent, these individuals may tend to act without reflection and to think without feeling. As a result, they may be perceived as being arbitrary and cold. Since convergers need to relate theory to practical applications, case studies, laboratory, field trips, and work experience are a very helpful part of their education.

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 convergers since they do not worry about practical aspects. They do share the AC aspect with convergers and are often more interested in ideas than in people. Many teachers, writers, lawyers, mathematicians, scientists, and engineers with a scientific bent are assimilators. Assimilators often do well in lecture classes, and their favorite learning style is in quadrant 2. Assimilators are systematic planners, but they may ignore the human aspect.

Accommodators prefer active experimentation and concrete experience (Quadrant 4). They are similar to convergers in that they like to act and to get things done. They differ from convergers 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. Accommodators 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 or group laboratory assignments. They prefer quadrant-4 activities. Accommodators may be seen as pushy and nontheoretical (a no-no in engineering education), and they rely heavily on trial and error.

Divergers are the opposite of convergers, preferring 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 divergent, they may not make decisions and will not get things done. Divergers often become artists, actors, personnel managers, counselors, and social workers. In a classroom, divergers do well in quadrant-1 activities such as group exercises, particularly brainstorming-type activities.

TABLE 15-2 DISTRIBUTION OF PREFERRED LEARNING STYLES (McCarthy, 1987)

Diverger (1)	Female (%)	Male (%)	Total (%)
Learning styles:			
Diverger (1)	25.0	19.4	23.0
Assimilator (2)	27.5	37.5	31.1
Converger (3)	14.8	23.5	17.5
Accommodator (4)	32.7	19.6	28.5
Dimensions:			
Concrete (1 plus 4)	57.7	39.0	51.5
Abstract (2 plus 3)	42.2	61.0	48.5
Reflective (1 plus 2)	52.5	56.9	54.1
Active (3 plus 4)	47.5	43.1	45.9

It is important to note that these are *preferred* styles, but that everyone has the capability to use and the need to develop all four styles. Working through Kolb's entire cycle automatically has students use all styles. In addition, every student has an opportunity to shine when the learning activity is in her or his favorite quadrant. The distribution of preferred learning styles for teachers and administrators was determined by McCarthy (1987) and is given in Table 15-2. It is interesting to note that higher percentages of men than of women are assimilators and convergers, which are the typical engineers, scientists, and technologists. Men tend to prefer abstract methods for taking in information, while women prefer more concrete approaches. These style preferences are not cast in stone. Students who are in a program which heavily emphasizes a given learning style tend to shift their preferences toward that style (if they survive). Also, 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 where they will be successful engineers. After school, accommodators tend to move toward management, sales, and marketing; divergers move toward personnel and creative positions. Convergers tend toward hard-core engineering jobs such as plant operations, design, and construction. Assimilators 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, convergers and assimilators are likely to find more kindred spirits among both teachers and their peers. Thus, it is the accommodators and the divergers who are most at risk in engineering education.

Teachers also have styles. If these styles differ from those of their students, the mismatch can cause problems. For example, assimilators emphasize logic, abstract theories, and ideas without applying them to practical problems. Convergers in the class do not consider the class to be practical and may not see the practical applications of the material. All students may have problems applying the material if later classes are taught in a convergent fashion. This mismatch often explains why engineering students are unable to use the mathematics they studied earlier. The teacher can help all students by including all aspects of Kolb's learning cycle. This provides some activities that are appropriate for each student, and helps each student broaden his or her repertoire of skills.

15.4. MOTIVATION

Regardless of the student's learning style and basic intelligence, he or she will not learn if not motivated. Unfortunately, "nobody can't teach nobody nothing" (Kolstoe, 1975, p. 61). Thus, student motivation is crucial to learning. 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 friendship, 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 discussed in terms of Maslow's theory of human needs and motivation.

15.4.1. 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. Since students need to see meaning in their studies, the motivation effort can focus on this. Once purpose is instilled, these students can become outstanding engineers.

3 The work ethic is absent. Many students coast through high school and find engineering painfully hard work. Installing a work ethic at this late date may be difficult, but it is important for success in engineering.

4 The background in prerequisites is inadequate. Success is very motivating, but with an inadequate background students may be unable to be successful in a specific course or in the entire curriculum.

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.

7 External problems are overwhelming. A death in the family, health problems, financial difficulties, relationship problems, and so forth, can prevent students from being motivated in their studies.

8 The student becomes overly anxious during tests or while doing homework. The discomfort caused by excessive anxiety can reduce motivation. High stress on tests is detrimental to all students but hits women harder than it does men (McKeachie, 1983). Anxiety and stress can be controlled by desensitization procedures (such as giving more tests), by relaxation methods (see Section 2.7), and by giving the student more control of the grade he or she will earn.

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 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).

15.4.2. Maslow’s Hierarchy of Needs

According to Maslow’s (1970) theory of motivation, which has become widely accepted, 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 Ph.D. in engineering who is lost in the woods and starving thinks only about food and rescue, not about 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, we 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

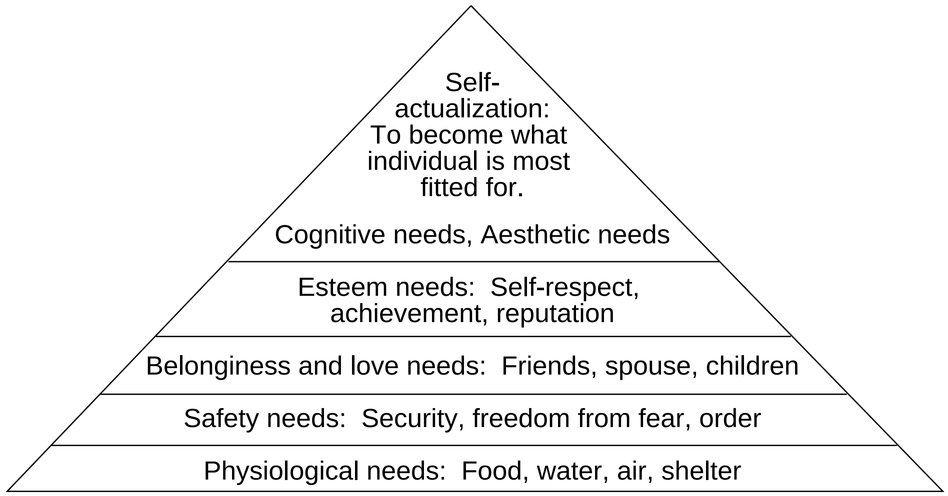

FIGURE 15-3 MASLOW'S HIERARCHY OF NEEDS

students, and 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 of students is significantly enhanced when students are integrated into the university both socially and academically (Smith, 1989). Academic integration includes contact with faculty and staff, involvement in the curriculum, and academic performance. Students who have made 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. To make contact with students the professor must at a minimum learn everyone's name. 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. It is interesting that significant contact almost always occurs for new engineering graduate students, 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 some time in introductory classes talking about the many joys and advantages of being an engineer helps some students get past a difficult period. Strong negative feedback attacks both the need for belonging and esteem. Unfortunately, the sting of negative feedback lasts much longer than the glow from positive feedback (Boschman, 1987). Professors need to 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 to include other learning styles can help these students feel they belong. These modifications were discussed in Section 15.2. A particularly important change for many students is to make learning more cooperative and less competitive (Smith, 1989). Cooperative group exercises and grading which 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.

A major need that can be fulfilled in class is that for esteem. Grades are often the most important motivating device (McKeachie, 1986) because they directly relate to the esteem needs, and grades are under the professor's control. Achievement, reputation, and self-respect can all be enhanced by good grades. The perception that one is doing well is very motivating. 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. When unfulfilled, the lower-level needs are more important. Good grades must also be seen to be achievable. Students with poor academic backgrounds and poor study habits quickly learn that they cannot achieve good grades. For them, grades are a demotivator. Remedial help and tutoring can help these students succeed. Another modification which involves considerable effort, but is extremely valuable for some students, is to use a flexible time frame and allow the students to spend more time learning. This can be done in mastery or self-paced classes (see Chapter 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 and by positive feedback. 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. For example, in basketball when a player fouls, the coach may praise the player for a good hustle and then correct him or her for the foul. Negative feedback should be avoided if at all 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 yelled at. 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 which 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. Motivation for doing tests and assignments appears to be highest when there is a fair but not certain chance for success (McKeachie, 1986). The professor should introduce assignments and tests with positive expectations for student performance. These positive expectations are in themselves motivating (Peters and Waterman, 1982; *What Works*, 1986). Success is motivating. It is worthwhile to ensure that there is some aspect of an assignment or 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 to be 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 a son or daughter earn a good salary. If satisfying parents helps meet belongingness and love needs, then the student may be positively motivated. For many students the salary helps to satisfy the need for esteem. Since salary after graduation is a long way off for a freshman or sophomore, the more immediate reinforcement of a summer 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 and undergraduate 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.

The highest level in Maslow's hierarchy, self-actualization, is the need for individuals to reach their potential. The need to self-actualize is what causes individuals 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. People require time to learn how to satisfy their needs. Thus 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.

Self-actualized individuals have a need to guide their own destiny. 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 make an effort to remove barriers that prevent students from achieving the joy of learning. The professor's enthusiasm and joy in learning the subject can be contagious. Sleeping students are not learning. Lecturing with energy, excitement, and some humor at least keeps students awake. And students enjoy classes more and learn more when the professor performs (see Section 6.3).

The force of curiosity is most evident in young children and in self-actualized individuals. Professors can use curiosity as a positive motivator in the classroom. For example, in a lecture questions can be asked and not be answered. We have found that questions which 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. Other variations of the socratic approach can be used. The important point is to ask questions which are thought-provoking for a group of students. 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 work life are more strongly motivated (Peters and Waterman, 1982). Students 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. Graduate students, in particular, can be given significant control over their projects and often respond with extraordinary energy.

All writers on motivation in college teaching (e.g., Eble, 1988; Ericksen, 1974; and McKeachie, 1986) note that teachers need to be creative in developing motivational techniques. 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 tutor 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 which increases the students' motivation. This is the famous "Hawthorne effect" (e.g., see Peters and Waterman, 1982). A professor can motivate classes by continually creating the Hawthorne effect by always experimenting. Professors control motivation in a class by their actions. If they give lip service to creative problem solving but always emphasize drill on homework and tests, the students will do drills. To obtain creative solutions there must be a focus on the activity. Many other examples could be cited.

15.5. CHAPTER COMMENTS

This chapter is not a complete picture of how individuals learn because that complete picture is not yet known or even sketched out. Individuals who prefer a global learning style may find this fragmentation disconcerting. However, enough is known and well documented by research that we have been able to make some firm recommendations about what is known to work. Many of the suggestions can be tried piecemeal with little effort. In the space available we have been unable to cover all the theories which can be used to understand learning and improve engineering education. In particular, the research on right- and left-brain functioning and the research on expert systems has not been included. The interested reader might start with Edwards (1989), Gazzaniga (1970), McCarthy (1987), and Springer and Deutsch (1989) for right-left brain research, and Smith (1987) for expert systems and artificial intelligence applications in engineering education.

Our experience in teaching this chapter 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.

15.6. SUMMARY AND OBJECTIVES

After reading this chapter, you should be able to:

• Extend Piaget's theory to the constructivism theory. 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 teaching.

• Delineate how auditory, kinesthetic, and visual styles affect learning and how they can be incorporated in engineering education.

• Explain Kolb's learning cycle and the implications of this theory in engineering education.

• Explain Maslow's theory of needs and discuss applications in engineering education.

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 15.6 (list dichotomous learning/teaching styles).
5 Do the third objective in Section 15.6 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.
7 Analyze the scientific learning cycle in terms of Kolb's learning cycle. Note which steps in the scientific learning cycle match quadrants in Kolb's cycle. Compare the order of steps. Both methods have been shown to work. Comment on why both approaches work. Which would you prefer to use? Why?

REFERENCES

Anderson, M. R., "Characterizations of the graduate career change woman in engineering: Recruitment and retention," *Proceedings ASEE/IEEE Frontiers in Education Conference*, IEEE, New York, 248, 1991.

Atkinson, G., Jr., and Murrell, P. H., "Kolb's experiential learning theory: A meta-model for career exploration," *J. Couns. Develop.* 66, 374, 1988.

Barbe, W. B., and Milone, M. N., "What we know about modality strengths," *Educ. Leadership*, 378 (Feb. 1981).

Belenky, M. F., Clenchy, B. M., Goldberger, N.R., and Torule, J.M., *Women's Ways of Knowing: The Development of Self, Voice and Mind*, Basic Books, New York, 1986.

Bodner, G. M., "Constructivism: A theory of knowledge," *J. Chem.Educ.*, 63, 873 (1986).

Boschman, E., *Ten Teaching Tools. Ten Secrets to Total Teaching Success*, Kendall/Hunt, Dubuque, IA, 1987.

Cashin, W. E., "Motivating students," Idea Paper No. 1, Center for Faculty Evaluation and Development, Kansas State University, Manhattan, KS, 1979.

Claxton, C. S., and Murrell, P. H., *Learning Styles: Implications for Improving Education Practices*, ASHE-EPIC Higher Education Report No. 4, Association for the Study of Higher Education, Washington, DC, 1987.

Dansereau, D. F., "Technical learning strategies," *Proceedings ASEE/IEEE Frontiers in Education Conference*, IEEE, New York, 165, 1986.

Eble, K. E., *The Craft of Teaching*, 2nd ed., Jossey-Bass, San Francisco, 1988.

Edwards, B., *Drawing on the Right Side of the Brain*, rev. ed., Jeremy P. Tarcher, Los Angeles, 1989.

Erickson, S. C., *Motivation for Learning*, University of Michigan Press, Ann Arbor, MI, 1974.

Felder, R. M., and L. K. Silverman, "Learning and teaching styles in engineering education," *Eng. Educ.*, 674 (April 1988).

Flammer, G. H., "Applied motivation—A missing role in teaching," *Eng. Educ.*, 519 (March 1972).

Gazzaniga, M., *The Bisected Brain*, Apple-Century-Crofts, New York, 1970.

Harb, J. N., Durrant, S. O., and Terry, R. E., "Use of the 4MAT system in engineering education," *Proceedings ASEE/IEEE Frontiers in Education Conference*, IEEE, New York, 612, 1991.

Hewitt, N. M., and Seymour, E., "A long discouraging climb," *ASEE Prism*, 1(6) 24 (Feb. 1992).

Kiewra, K. A., Memory-compatible instruction," *Eng. Educ.*, 285 (Feb. 1987).

Kirby, P., *Cognitive Style, Learning Style, and Transfer Skill Acquisition*, Information Series No. 195, Ohio State University, National Center for Research in Vocational Education, Columbus, OH, 1979.

Kolb, D. A., *Experiential Learning: Experience as the source of learning and development*, Prentice-Hall, Englewood-Cliffs, NJ, 1984.

Kolb, D. A., *Learning Style Inventory*, McBer & Co., Boston, 1985.

Kolstoe, O. P., *College Professoring: Or, Through Academia with Gun and Camera*, Southern Illinois University Press, Carbondale, IL, 1975.

Kurfiss, J. G., *Critical Thinking: Theory, Research, Practice, and Possibilities*, ASHE-ERIC Higher Education Report No. 2, Association for the Study of Higher Education, Washington, DC, 1988.

Lawson, A. E., Abraham, M. R., and Renner, J. W., *A Theory of Instruction: Using the Learning Cycle to Teach Science Concepts and Thinking Skills*, Monograph *1*, National Association for Research in Science Teaching, Cincinnati, OH, 1989.

Lowman, J., *Mastering the Techniques of Teaching*, Jossey-Bass, San Francisco, 1985.

Maslow, A., *Motivation and Personality*, 2nd ed., Harper and Row, New York, 1970.

McCarthy, B., *The 4MAT System. Teaching to Learning Styles with Right/Left Mode Techniques*, EXCEL, Barrington, IL, 1987. (The format of this book may seen strange to engineers, but the book rapidly gets into practical and theoretical details.)

McKeachie, W. J., “Student anxiety, learning and achievement,” *Eng. Educ.*, 724 (April 1983).

McKeachie, W. J., *Teaching Tips*, 8th ed., D.C. Heath, Lexington, MA, 1986.

Mettes, C. T. C. W., Pilot, A., Roosink, H. J., Kramers-Pals, H., “Teaching and learning problem solving in science. Part II: Learning problem solving in a thermodynamics course,” *J. Chem. Educ.*, 58(1), 51 (Jan. 1981).

Murr, L. E., “Engineering education in the visual culture,” *Eng. Educ.*, 170 (Dec. 1988).

Peters, T. J. and Waterman, R. H., Jr., *In Search of Excellence. Lessons from America’s Best-Run Companies*, Harper and Row, New York, 1982. (Although about business, many of the ideas are directly applicable to education.)

Pintrich, P. R., “Implications of psychological research on student learning and college teaching for teacher education,” in W. R. Houston, M. Haberman, and J. Sikula (Eds.), *Handbook of Research on Teacher Education*, MacMillan, New York, 926—857, 1990.

Robinson, J. E., and Heinen, J. R. K., “Some implications of cognitive styles for the teaching-learning process,” *Educ. Res. Methods* 7(4), 87 (Summer 1975).

Schmeck, R., “Improving learning by improving thinking,” *Educ. Leadership*, 38, 384 (1981).

Smith, D. G., *The Challenge of Diversity: Involvement or Alienation in the Academy?* Report No. 5, School of Education and Human Development, The George Washington University, Washington, DC, 1989.

Smith, K. A., “Educational engineering: Heuristics for improving learning effectiveness and efficiency,” *Eng. Educ.*, 274 (Feb. 1987).

Smith, K. A., Stanfield, A. M., and Macneal, R., “Constructing knowledge bases: A methodology for learning to synthesize,” *Proceedings ASEE/IEEE Frontiers in Education Conference*, IEEE, New York, 374—381, 1985.

Springer, S. P., and Deutsch, G., *Left Brain, Right Brain*, 3rd ed., W. H. Freeman, New York, 1989.

Stice, J. E., “Using Kolb’s learning cycle to improve student learning,” *Eng. Educ.*, 291 (Feb. 1987).

Svinicki, M. D. and Dixon, N. M., “The Kolb model modified for classroom activities,” *Coll. Teach.*, 35(4), 141 (1987).

Terry, R. E., Durrant, S. O., Hurt, P. K., and Williamson, K., “Implementation of the Kolb learning style theory in a faculty development program at Brigham Young University,” *Proceedings ASEE Annual Conference*, ASEE, Washington, DC, 54, 1991.

Tobias, S., *They’re Not Dumb, They’re Different*, Research Corporation, Tucson, AZ, 1990. [Copies of this book can be obtained directly from the Research Corporation, 6840 East Broadway Boulevard, Tucson, AZ 85710-2815.]

Todd, R. H., “The how and why of teaching an introductory course in manufacturing processes,” *Proceedings ASEE/IEEE Frontiers in Education Conference*, IEEE, New York, 460, 1991.

Waldron, M. B., “Modeling of visual thinking and creativity,” *Proceedings ASEE Annual Conference*, ASEE, Washington, DC, 488, 1986.

What Works, U.S. Department of Education, Washington, DC, 1986. (Copies can be obtained by writing to *What Works*, Pueblo, CO 81009.)

Woods, D. R., Wright, J. D., Hoffman, T. W., Swartman, R. K., and Doig, I. D., “Teaching problem solving skills,” *Eng. Educ.*, 238 (Dec. 1975).