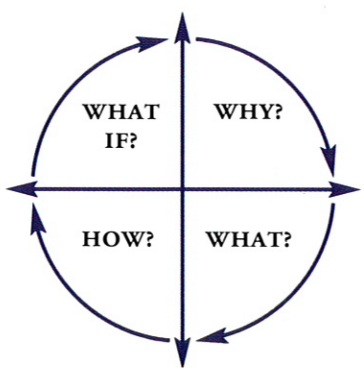
·Teaching through the Cycle·

APPLICATION OF LEARNING STYLE THEORY TO ENGINEERING EDUCATION AT BRIGHAM YOUNG UNIVERSITY



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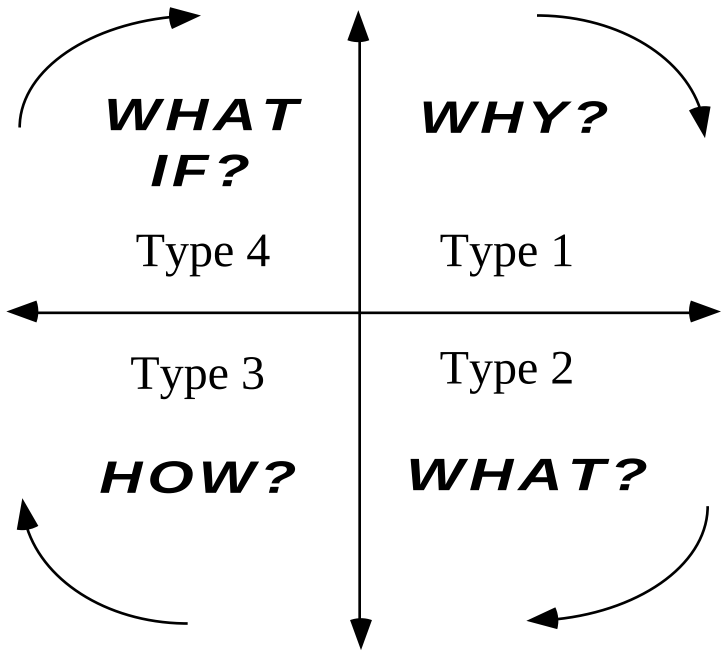
PREFACE

Increasing demands are being placed on undergraduate engineering education including a rapidly expanding knowledge base and a variety of societal problems which are inherently interdisciplinary in nature. As a result, the technical portion of a typical undergraduate engineering curriculum represents a diminishing fraction of the total information needed by our students during their professional careers. Consequently, it is imperative that we, as engineering educators, accomplish much more than information transfer. Students need to be taught how to learn so that they will be prepared for a lifetime of learning. We must prepare students with a sound knowledge of fundamental principles and a demonstrated ability to think and act independently. We believe that more effective teaching methodologies, extending beyond the traditional cognitive-based, teacher-centered lectures, will play an important role in the accomplishment of this objective. However, the implementation of such methods requires an awareness of the alternatives; a willingness to dedicate the personal resources needed to effect change; and the existence of an academic system which provides the opportunity for such change (e.g. with regards to a reward system which encourages teacher development).

The purpose of this monograph is to provide a resource for the enhancement of engineering education based on learning style theory. The methodology described here represents an alternative to the traditional (and widely practiced) form of engineering education. The material is organized into three distinct sections. Section I contains a discussion of the learning theory which serves as the foundation for the material in subsequent sections. Section II provides a resource of learning activities for use by engineering educators. The final section documents the application of the learning theory in a teacher development program at Brigham Young University. The content of each of these sections is summarized in the paragraphs which follow.

Section I

This section describes four learning styles or types which were derived from the manner in which individuals perceive and process information [1,2]. Each of these learning styles can be associated with a favorite question, namely: 1) "Why?", 2) "What?", 3) "How?", and 4) "What if?". These four questions form the basis of the Kolb Learning Cycle as shown on the next page. All four of the learning styles are present in the typical engineering classroom, although engineering fields are dominated by learners who like to ask the questions "What?" and "How?". Faculty also have teaching preferences which are correlated with their preferred learning styles. The traditional professor-dominated lecture is a Type 2 activity and is preferred by the majority of engineering faculty. The formal lecture is also the instructional activity of choice for many engineering students. However, the needs of all learners are best met by spending a portion of the time teaching to each of the learning preferences or "teaching through the cycle." In addition, by teaching through the cycle and answering the questions "Why?", "What?", "How?", and "What if?", the ability of all students to learn is enhanced. In other words, as students learn to traverse the Learning Cycle by themselves, they become more efficient and independent thinkers and learners. Finally, the Learning Cycle provides a practical model which engineering faculty may use as a basis for improved instruction of students.



Section II

Section II of the monograph is designed to facilitate practical application of learning style theory in the engineering classroom. The bulk of this section examines issues related to "teaching through the cycle." Both the principal objectives and the role of the teacher in accomplishing those objectives are defined for each of the four quadrants in the Learning Cycle. A list of learning activities pertaining to the dominant learning style is also provided for each quadrant. A discussion of several of these activities follows the activity list for each quadrant. Issues related to individual implementation of the material are also discussed. Finally, sample lesson plans are included for several engineering courses.

Section III

Section III documents the use of learning style theory in a *teacher development program* at Brigham Young University. The program was made possible through the efforts of the Teacher Development Committee in the College of Engineering and Technology. The dean's office played a key role in supporting the program and allocating the resources necessary for its success. The technical material for the program was provided by Dr. Kenneth J. Williamson and Dr. Pamela Hurt who served as consultants. The objective of the program was to enhance student learning by introducing more effective teaching methodologies into the curriculum. This section provides a step-by-step description of the program implementation; illustrates the extent of faculty involvement; and identifies several obstacles which had to be overcome in order to effect change. The success of the program is documented in several personal statements from participating faculty members.

This monograph is intended to be a resource for those interested in incorporating these concepts into their teaching methodology. We are confident that you will find this material to be a valuable tool to use in the education of tomorrow's engineers.

ACKNOWLEDGEMENTS

We wish to acknowledge the dean's office in the College of Engineering and Technology at Brigham Young University which provided both financial and moral support for this work. We would also like to thank the college Teacher Development Committee for their efforts. A special thanks goes to the engineering faculty whose participation was essential to the success of the teacher development program. We also acknowledge the important contributions of Dr. Julie Sharp, Department of Chemical Engineering at Vanderbilt University, in the section on Writing Across the Curriculum and the helpful editing suggestions of Dr. Lynn Sorenson, Assistant Director for Instructional Development of the Faculty Center at Brigham Young University. We especially wish to thank the secretarial staff in the Department of Chemical Engineering for making order out of chaos.

SECTION I

THEORY

The purpose of this section is to introduce elements of learning style theory and to show how the learning cycle can be a model for teaching.

BACKGROUND

John Dewey defined education as "the process of controlling the educational experience." This definition recognizes the great responsibility that we, as educators, have to create an environment which facilitates and enhances student learning. We must decide what, when, and how learning will occur. We believe that a large number of options are available to us as engineering educators when we make these decisions. From these options, it is our responsibility to choose the ones that best fit us as teachers, our institutional-centers of learning, and our students as seekers of enhanced knowledge and abilities.

We will first examine the learning process in order to develop a rational basis for the making of such decisions.

THEORY OF LEARNING STYLES

A common mistake made by university faculty is to assume that *students learn in the same manner as the individual faculty member*. In practice, this assumption often degenerates to something like "*all good students learn in the same manner as I do*." Consequently, students with different learning approaches are often dismissed as either lacking intelligence or as being non-cooperative.

Educational theorists have identified that people perceive (how we take things in) and process (how we make things a part of us) new information differently [1,2]. Some people prefer to **perceive** or grasp a new experience by feeling (sensing) their way through the experience. Others prefer to perceive by thinking and making use of symbols or conceptual models. The perceiving function can be represented as a line with the words "feeling" and "thinking" at the opposite ends of the line. The balance between perception by feeling or by thinking for an individual can be represented by a point on this line. In **processing** new information, some people watch and observe while others become personally and actively involved. Again, we can imagine a line with "watching" and "doing" at the opposite ends. Based on the two dimensions of perceiving (grasping) and processing (transforming), Kolb identified four different types of learners as shown in Figure 1 [1].

In quadrant 1, learners perceive in a feeling mode and process in a watching mode. Similarly, each of the other quadrants leads to specific learner types. Kolb referred to these four types of learning as learning styles. According to Claxton and Ralston, the term "learning styles" refers to the preferred manner in which students respond to and use stimuli in the context of learning [3]. Note that the Kolb model is not the only learning style model found in the literature. However, it is the model which will be used throughout this document. All four of the Kolb learning styles are found in nearly equal proportion in the general population [1,2]. In addition, our research has shown that all four learning styles are present in each engineering class we teach.

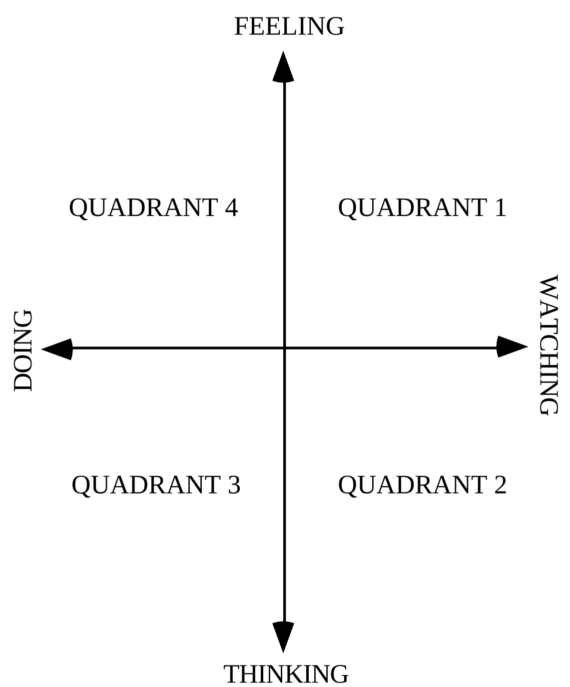


Figure 1. Elements of Learning and Learning Styles.

Within the academic community, considerable interest has been generated concerning the idea of different student learning styles [4-10]. The trend is shifting away from searching for the "best" method of teaching toward the development of methods that provide instructors and students a "smorgasbord" of activities. The basic paradigm associated with the "smorgasbord" approach is that students learn in a variety of styles and that teaching effectiveness is enhanced by teaching to each learning style at least a portion of the time. Such an approach is termed a learning style format.

Kolb's model of experiential learning provides a framework for understanding learning styles [1]. In his model, Kolb defined the opposite ends of the perception axis as concrete experience (feeling) versus abstract conceptualization (thinking), and the processing axis as reflective observation (watching) versus active experimentation (doing). An extended description of each of these is found in the paragraphs which follow.

Concrete experience (CE), sensing/feeling: In concrete experience, the learner is immersed in the new experience. Feeling is emphasized over thinking or logic. The strategy is to be open, adaptable, intuitive and to maximize involvement. The stimulus from the environment needs to be sorted and selected so that feeling and valuing are dominant mind activities. Abilities in the CE area include good interpersonal relationships and sensitivity to personal values of all involved.

Abstract conceptualization (AC) or thinking: In abstract conceptualization, the learner attempts to logically and systematically organize information into concepts, theories, and ideas. The emphasis is on thinking as opposed to feeling or sensing. The learner is concerned with building general theories rather than intuitively understanding specific situations or areas.

Reflective observation (RO) or watching: In reflective observation, the learner becomes the objective observer. The strategy is to separate oneself from the particular experience and to observe the occurrence from as many different views as possible. The dominant mode is patient watching and personal reflection in order to make judgments.

Active experimentation (AE) or doing: In active experimentation, the learner is directly involved with the environment. The world is addressed, tested, and manipulated to obtain a response. The strategy is to find what actually works and to obtain practical results. The dominant mode is testing.

Kolb claims that the four learning styles exist as two distinct polarities of CE versus AC (perceiving) and RO versus AE (processing) as represented by the two axes previously defined in Figure 1. For example, this condition of polarity results in a mutual exclusion of involvement in the RO activities and involvement in AE activities. This is fairly obvious as learners cannot be both "removed and reflective" and "active and involved" at the same time. However, it should be pointed out that we are discussing *preferred* ways of perceiving and processing. Other methods of perceiving and/or processing material rather than the preferred method can also be used by individuals.

. . . the four learning styles are preferred ways of perceiving and processing . . .

Determining Learning Styles

The preferred learning style of any student can be determined by using the Kolb "Learning Style Inventory" or LSI [11]. The LSI is a forced-selection preference test that requires identification with various descriptors of the four learning abilities. The test has been administered to thousands of students to determine their preferred learning styles. Figure 2 shows a typical result of a learning style inventory where the distance along each of the four axis is proportional to the degree to which an individual prefers the perceiving and processing functions. The results are for a learner with an AC-AE preference.

While the AC-AE style of learning is preferred in Figure 2, each of the other three modes are represented as well. This will be the case for every person, i.e., that each of the four learning styles is represented. However, it will be true that one particular learning style will be dominant and hence is "preferred." Learning styles have been shown to correlate with choice of professions, with engineering students tending to prefer the RO-AC and the AC-AE modes of learning [1].

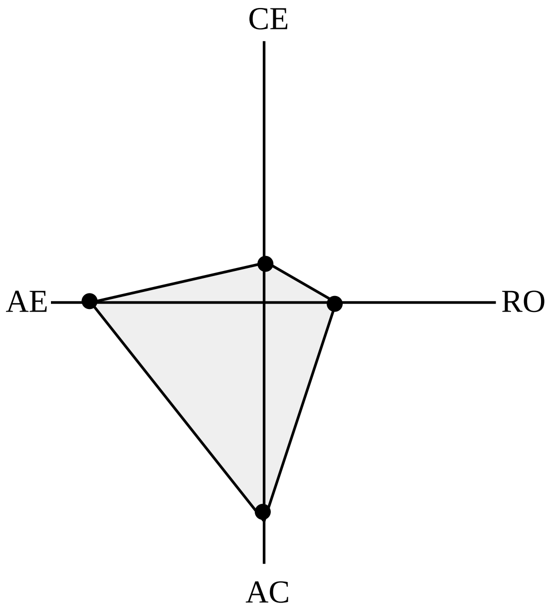


Figure 2. Results of a learning style inventory for a AC-AE preferred learner.

Kolb identified the four distinct learning styles as: divergers (Type 1 learners); assimilators (Type 2 learners); convergers (Type 3 learners); and accommodators (Type 4 learners) as shown in Figure 3.

Some generalized characteristics of each learning style are described below [1,2]. In addition, Figure 4 provides a summary of likes and dislikes for each of the four learning styles.

Type 1 Learners: These students like to integrate experience with their own personal values and feelings. They view their learning environment from many perspectives, and prefer to listen and share ideas. They must be personally involved and work constantly for harmony in their lives. They are creative and innovative. In relation to motivation, they seek to understand the value of the proposed learning and to know "why" the proposed learning would relate to themselves. They are termed divergers because they tend to be highly individualistic and seek maximum personal choice. Their favorite type of question is "Why?" as in "Why is this concept of enough value that I should learn it?"

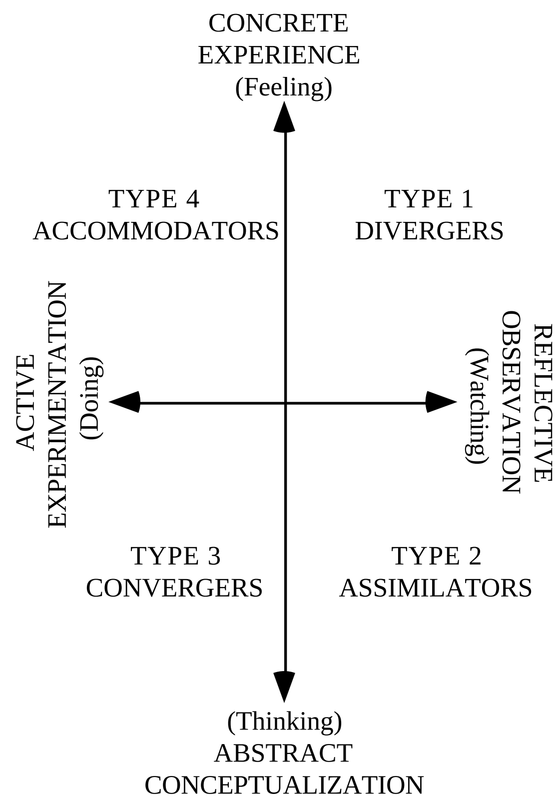


Figure 3. Learning Styles.

Type 2 Learners: These students tend to integrate observations with existing

LIKES

Type 4

Integrate experience and application.
Learn by trial and error.
Discover new ideas for themselves.
Get excited by new things.
Adapt to new situations.
Reach good conclusions by intuition.
Take risks.

Favorite question: **IF**? (i.e. What if?)

Type 1

Integrate experience with Self.
Listen and share ideas
View from many perspectives.
Work for harmony.
Be personally involved.
Be innovative.
Clarify values.

Favorite question: **WHY?**

Type 3

Integrate theory and practice.
Test theories and apply common sense.
Solve "down-to-earth problems."
Think strategically.
Use skills.
Know how things work.

Favorite question: **HOW?** (i.e. How does this work?)

Type 2

Integrate observations into what is known.
Seek continuity.
Know what experts think.
Think through ideas.
Think linearly.
Work with detail
Critique information and collect data.

Favorite question: **WHAT?**

DISLIKES

Type 4

Long lectures.
Teacher-oriented classrooms.
Standard routines.
Repetition and drill.
Assignments without options.
Knowledge for its own sake.

Type 1

Timed tests, pop quizzes.
No student interaction.
Insensitive teachers.
Individual work.
Skill development.
Lack of thinking time.
Coverage rather than depth.
Colorless environments.

Type 3

Reading from books.
Memorization.
Confined nature of lectures.
Lack of application.
Restricted environments.
Group work.
Lack of hands-on work.
Labs that don't work.
Written assignments.

Type 2

Information out of sequence.
Multiple authorities.
Pass/fail grading.
Criticism.
Group projects.
Disorganization.
Unknown expectations.

Figure 4. Characteristics of Different Learning Types

knowledge. They are strong conceptualizers and use deductive problem solving. They often seek continuity between the "new" and the "old" and look to obtain knowledge from authorities. They work well with detail and data; however, if the data do not fit the model, then the data are immediately suspect. They are called assimilators because they are always seeking to assimilate new ideas and thoughts. Their favorite question is "What?" as in "What do I need to know to solve this problem?"

Type 3 Learners: These students integrate theory and practice, and use both abstract knowledge and common sense. They like to solve practical problems, especially under a variety of constraints. They tend to think strategically, and act pragmatically. Often they collect intellectual and hands-on skills which are saved for the time that the skill is required to solve a problem. They typically use a combination of deductive and inductive problem-solving techniques. They are called convergers because they seek for "the solution" to practical problems. Their favorite question is "How?" as in "How does this work?" or "How can I solve this problem?"

Type 4 Learners: These students tend to be highly active and creative. They integrate experience into application and often new experience into immediate applications. They often learn by trial-and-error and discover new knowledge without the assistance of an authority. They tend toward the use of inductive problem-solving techniques. They are highly intuitive and often generate excellent conclusions based solely on intuition. They get excited by new and challenging situations and are natural leaders and performers. They are called accommodators because they easily adapt to new situations. Their favorite question is "What if?" as in "What if we did something different to solve this problem?"

Our surveying of undergraduate engineering students has shown that there is about 10% Type 1 learners, 40% Type 2's, 30% Type 3's, and 20% Type 4's.

Information on students' learning styles can be used in the following two manners [3]:

1. by the student to improve his/her educational efforts through an understanding of the strengths and weaknesses of a particular style, and

2. by faculty to improve planning for the learning experience and to improve student-faculty interaction.

TEACHING STYLES

Not only do students have preferred learning styles, but faculty have preferred teaching styles which correspond to their own individual learning style. Characteristically, these teaching styles can be described in four types.

Type 1 Teachers: These teachers focus on the personal development of the students. They tend to develop good relations with students and to be highly motivating. Their classrooms are filled with cooperation and discussion of values and meaning. In engineering classes, they like to engage students in discussions of life as an engineer in the profession and in society. Their teaching environment of choice involves questioning and class discussion.

“...faculty have preferred teaching styles..."

Type 2 Teachers: These teachers focus primarily on the transmission of knowledge. In their classrooms, the teacher is the authority and the students learn in a hierarchal manner from the teacher. Most textbooks are written by Type 2 teachers, so these teachers often follow closely the textbook material. Their teaching environment of choice is professor-centered lectures.

Type 3 Teachers: These teachers primarily focus on promoting productivity and competence. They want to teach students the skills necessary for being a "good" engineer. They tend to be highly independent and want their students to be independent. Their teaching environment of choice is the traditional lecture format coupled with laboratories and out-of-classroom experiences.

Type 4 Teachers: Type 4 teachers encourage experiential learning. While Type 1 teachers focus upon relationships, Type 2 teachers on knowledge, and Type 3 teachers on skills, Type 4 teachers encourage self-discovery. They tend to be stimulating and dramatic, and hope to expand students' intellectual boundaries. They operate in all teaching environments and will mold the environments to meet their needs.

From our surveying of engineering faculty, about 10% are Type 1 teachers, 50% Type 2, 30% Type 3, and 10% Type 4.

From the description of teaching styles and the distribution of styles among faculty, we can see clearly one motivation behind the professor-dominated formal lecture format which is so prevalent in engineering education. It is a learning environment that is preferred by at least half of our engineering educators and one that is readily accepted (and preferred) by a large fraction of our students. It is also true that most engineering faculty members learned "how to teach" from observing their own teachers, who themselves used the professor-dominated lecture format as the teaching method of choice. Finally, lectures are an efficient way to transfer large amounts of information. Hence, lectures have become the dominant paradigm for engineering education. However, this does not imply that lectures are the ideal from an educational perspective.

LEARNING ACTIVITIES

Because students have different learning preferences, it is important that faculty provide activities for students that will allow them to feel comfortable in the learning environment. When we restrict ourselves to basically one way of presenting material, e.g., professor-dominated formal lectures, we are not addressing the different learning styles of our students. In addition, the ability of all of our students to learn is enhanced as they are required to function in learning styles other than their preferred mode. There is a large number of activities that we can use to address the different learning styles.

Learning activities can be highly varied and can involve any number of linkages - student-teacher, student-student, student-object, student-information, and student-evaluation. Professional educators have a responsibility to control the process so that students experience all of these learning avenues. Group projects can link students to other students; out-of-class room experiences can involve many exciting and information-rich objects; and a variety of evaluations force students to look at information in different ways. Again the choices available are numerous.

A way to think about the options available in learning activities is the use of the common institutional categories of lectures, recitations, laboratories, out-of-classroom experiences, and evaluative tools. Some examples are shown in Table 1 and discussed later in the monograph.

Faculty can alter the learning environment through the use of a variety of these options. As professional educators, we need to be knowledgeable about the options, how they are accomplished, and their advantages and disadvantages. Table 1 can be viewed as a teaching "tool kit ".

THE KOLB LEARNING CYCLE AS A MODEL FOR TEACHING

It is important that each student learn how to function in all of the four quadrants (i.e., obtain answers to each of the questions, Why?, What?, How?, and What if?). These four questions represent the internal structure of the learning cycle which is a pattern for learning new concepts. A combination of the learning modes from all four learning styles produces the highest level of learning [1]. Most engineering educators have learned how to answer these questions during their graduate education while working on a doctorate in a specialized field. A major challenge in education is to help our undergraduate students learn how to address all of these questions. To do this, we need to provide various instructional activities that will address the different learning styles and move the students through the learning cycle.

. . . learning occurs by passing through the four quadrants . . .

In the learning cycle, immediate experience (CE) creates a need for learning which transfers to reflective observation (RO) of the experience which is followed by the introduction of concepts (AC) to integrate the immediate experience into what is known. After integration, testing is induced (AE) and, because this action results in new experiences, the cycle repeats (see Figure 5).

Table 1. VARIOUS INSTRUCTIONAL ACTIVITIES

TYPES OF LECTURES

Formal lecture, thinking tone
Formal lecture, feeling tone
Lecture with visual aids
Lecture with demonstrations
Lecture with prompted responses
Lecture with incentive quiz
Lecture with programmed notes
Student lectures
Role playing
Feedback lecture
Interactive lecture
Socratic lecture

TYPES OF OUT-OF-CLASS EXPERIENCES

Short field trips
Long field trips
Internship
Co-op with industry
Student contest
Large seminar
Professional meeting
Library search
Teaching assistant
Group project

TYPES OF RECITATIONS

Question and answer
Tutorial (one-on-one)
Problem solving by instructor
Problem solving by students
Problem solving by groups
Student presentations
Seminars
Computer-aided instruction
Guided design

TYPES OF PERFORMANCE EVALUATION

Objective test
Subjective test
Oral test
Pop quiz
Out-of-class test
Laboratory test
Homework problems
Individual report
Group project report

TYPES OF LABORATORIES

Class experiment
Group experiment
Training
Instructor demonstration
TV demonstration
Experiment and design
Capstone design
Computer simulation
Games
Independent research
Group research
Field work
Think tanks
Quality circles

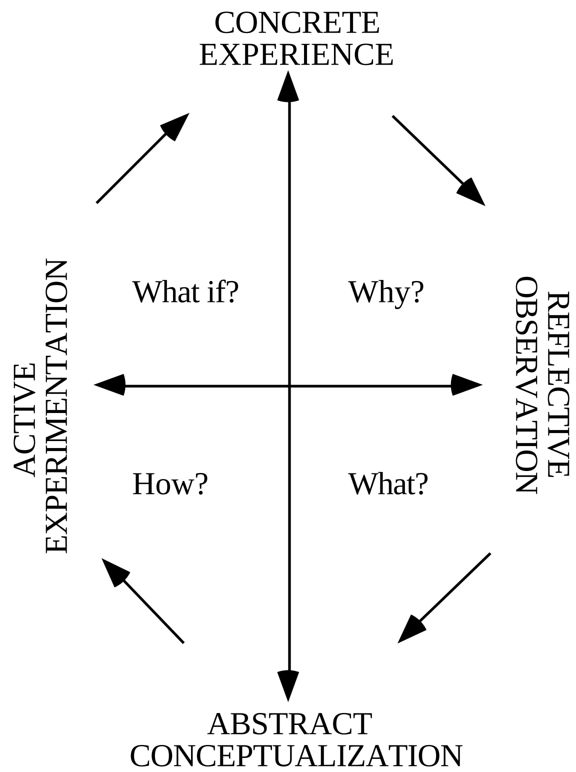


Figure 5. The Kolb Learning Cycle

Based on the work of Kolb and others, McCarthy developed the 4MAT learning system which she applied to primary and secondary education [2]. The 4MAT learning system is based on the supposition that learning is best served by passing through the four quadrants as shown in Figure 5. The cycle can be thought of as answering the various questions associated with "Why?", "What?", "How?", and "What if?".

Movement around the learning cycle can be accomplished by the proper choice of learning environment/interaction for the individual quadrants. Most choices can be intuitively placed in a particular quadrant; for example, "formal lectures, thinking tone," is clearly a quadrant 2 activity. Other choices are more difficult to place and may require actual experience. However, using Table 1, faculty may generate a teaching plan to move through the learning cycle. The next section of this monograph provides examples of activities in each quadrant, and it is designed to aid faculty members in choosing appropriate activities.

Faculty who adopt learning style theory and incorporate the learning cycle into their teaching methodology and philosophy appear to have remarkable success. Increased learning and student satisfaction coupled with increased faculty satisfaction are often noted. Stice reported potential advantages from the application of learning style theory to engineering education which included greater information retention, a very important goal for Type 2 teachers [7]. Later in the monograph, we will document some of our own and our colleagues' experiences and feelings. Learning style theory has also been applied with success in industrial research and development environments [12].

THE KOLB LEARNING CYCLE AND EDUCATIONAL GOALS

The major advantages of applying the learning cycle to engineering education include greater student satisfaction and the support of the four educational goals of improved thinking, problem-solving, communication and the development of self-motivated learners.

Student satisfaction often increases since each new concept in a course is taught through the four learning preferences and thus reaches all four learning styles. The effective response of the students is something like "I am being personally listened to." The use of the learning cycle will improve student satisfaction for the students with learning styles not typically reached by a lecture-dominated learning environment/interaction. However, the primary reason for choosing to plan the educational experience around the learning cycle is that the learning cycle supports the educational goals mentioned above.

Persons who become excellent learners will develop good skills in all four learning styles and will travel through the learning cycle rapidly. This can be seen as the ultimate goal for helping students to become individualized self-motivated learners. This is probably the greatest advantage of the learning style theory format in that the use of the learning cycle will ultimately allow students to learn independently of the professor and the university environment.

. . . excellent learners have skills in all four learning styles . . .

This advantage cannot be overstated. Our graduates often lack the confidence to be self-learners. The source of this reality can probably be traced to the typical learning environment/interaction that involves the professor-dominated lecture format. Such a format can only encourage dependence of the learner upon both the professor and the classroom.

In addition to helping students become independent, the use of the learning cycle encourages students to use their thinking, problem-solving, and communication skills with each pass around the cycle. This is a process of repetitive practice where modeling from the professor is supplemented with nearly constant feedback. The thinking efforts are concentrated in quadrants 1 and 2; the problem-solving in quadrants 3 and 4; and the communication in quadrants 4 and 1. In this fashion, use of the learning cycle promotes the development of the higher level problem-solving skills of analysis, synthesis, and evaluation. The importance of these skills has been firmly established by Bloom [13, 14]. These skills are clearly necessary for advanced engineering education because they are important components of engineering design [15,16]. In fact, many of the inherent difficulties in teaching open-ended engineering design are probably due to such courses requiring analysis, synthesis, and evaluation skills that are not encouraged in a professor-dominated lecture format.

SUMMARY

In this section we have examined learning style theory and have defined four dominant learning styles. It was shown that each of the four styles is characterized by a favorite question namely: Why?, What?, How?, and What if?. All of the different learning preferences are present amongst the students in our classrooms. It is therefore important to spend a portion of our time teaching to each of the learning preferences in order to meet the needs of all learners. It is also important to help our students become independent thinkers and learners by teaching them to traverse all four quadrants of the cycle. The learning cycle provides a practical model which engineering faculty may use as a basis for improved instruction of students.

SECTION II

APPLICATION OF THE LEARNING CYCLE TO THE ENGINEERING CLASS

The purpose of this section is to provide instructional activities that can be used both in and out of the classroom. Activities are described that will address each of the four learning styles discussed in the previous section. The section is divided into four subsections. The first presents an overview of instructional activities. The second contains specific activities related to questioning. The third subsection presents activities which relate to the concept of writing across the curriculum. The fourth contains ideas regarding implementation of the learning cycle in the classroom and sample lesson plans.

1. OVERVIEW OF INSTRUCTIONAL ACTIVITIES

INTRODUCTION

The purpose of this sub-section is to explore the application of learning style theory to enhance learning in the engineering classroom. In other words, the intent is to facilitate the practical application of the theory. To do this, the sub-section has been organized into two parts: l) Background, and 2) Teaching Through the Cycle. We believe that all engineering educators can apply these principles and techniques to one extent or another in their teaching; we do not view this material as simply "a nice idea for those who are not doing research." The real strength of the approach is that it provides a *model* which can be used to examine, evaluate, and improve engineering educators' classroom performance.

BACKGROUND

In Section I we identified the need for all learners to both perceive and process information. Kolb identified four general learning styles which are a function of how we prefer to perceive and process information. Each of these learning styles has been characterized by a favorite question namely: l) Why?, 2) What?, 3) How? and 4) What if?. These four questions can be used as the basis for a "learning cycle" as shown in Figure 6. This cycle has been applied to primary and secondary education by McCarthy who refers to the process as the 4MAT System [2]. Characterization of each quadrant by a single question is, of course, a simplification, although it is adequate for our present purposes.

Motivation

As you will recall from the previous section, there are two principal motivations for the application of the Kolb cycle to engineering education. The first objective is to reach all of our students by spending time teaching to each of the different learning styles. Statistics support the existence of all of the different types of learners in each engineering class that we teach. In contrast, the traditional professor-dominated lecture favors a single learning style. In general, the needs of all learners are best met through the use of a variety of activities from each of the four quadrants.

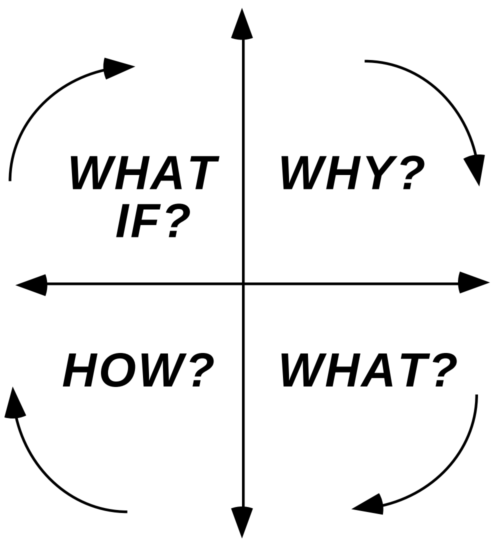


Figure 6. The Learning Cycle.

The second objective is to enhance learning by helping our students traverse the full learning cycle. The learning cycle not only provides a model which we can use to improve our teaching, it provides a model which our students can use to teach themselves. Failure to consistently traverse the full cycle is likely to produce deficiencies in the abilities of those whom we teach. For example, we have all observed students who were very good at the mechanics of problem solving, but lacked the vision and perspective necessary to recognize the problem. We also frequently observe the failure of students to apply the principles learned from one problem to another problem which is slightly different but governed by the same principles. On the other hand, consistent teaching through the cycle will help our students become better and more independent learners and thinkers.

. . . the learning cycle provides a model which our students can use to teach themselves . . .

Relationship to Current Teaching Style

The purpose of this monograph is, simply, to share a tool which we feel has great potential in the engineering classroom. You will probably find, as we did, that many of the things which you are already doing fit nicely into the learning cycle format. The learning cycle provides a useful model for organizing and improving classroom instruction. Obviously, some additional effort is required to apply the principles discussed in this document. However, one of the principal purposes of the document is to reduce the time and effort required for such application.

We believe the effectiveness of teaching should be evaluated on "what is caught and not what is taught." Studies show that the average attention span of our students is approximately 20 minutes [17]. Therefore, a significant fraction of a 50-minute period which is spent giving lectures may be used inefficiently when judged from the standpoint of student learning. Also, most of us are currently trying to teach too much information; therefore, it may be necessary to cut some material out of our classes in order to improve the percentage of that which is actually retained. A reduction in the amount of information taught does not imply less effort on the part of the students. In fact, our objective is to increase the level of student commitment to the learning process at all stages. The desired result is students who are independent learners and independent thinkers. We believe that you will find that the application of the learning cycle to the engineering classroom rewarding and exciting for instructors and students alike.

TEACHING THROUGH THE CYCLE

We will now explore teaching in each of the four quadrants of the learning cycle. At each step we will examine l) the principal objectives of the particular quadrant and the role of the teacher in accomplishing those objectives, and 2) learning activities pertaining to the dominant learning style in the quadrant. Note that the same type of activity may be used in multiple quadrants, although the emphasis and objectives of the activity will be different in each quadrant.

I. Quadrant One

Objectives

The first quadrant is characterized by the question **WHY**?. It is in this quadrant that we establish a "feel" for the subject to provide a foundation for the formal information which follows in quadrant two. It is also in this quadrant that we help motivate students to desire to learn about the topic that we are teaching. Several specific objectives can be defined:

Introduce the subject. Discuss what you are going to do. Help the students develop a "feel" for the technical material which will follow. It is also a good idea to establish goals for instruction and to share those goals with the students.

Provide the big picture. It is essential to connect the subject material to the student's previous experience. By identifying the overall picture, you are helping the students develop a connection between new information and other information which has been previously processed. This connection will help the students appreciate the importance of the information. It will also enhance the ability of the students to retain and retrieve the information later.

Provide meaning. Students need to be able to answer the question "Why am I learning this?" Help the students understand how this information is relevant to their lives now, and how it relates to their future (e.g. employment).

Generate enthusiasm. We cannot expect our students to be interested and excited about the material we are teaching if we do not possess and convey that same excitement. We must be enthusiastic about what we teach.

Show respect and interest. Let the students know that you respect their abilities and that you are concerned about helping them learn the material.

As seen from these objectives, the principal role of the teacher in this quadrant is that of a **MOTIVATOR** who personalizes the material and motivates students to learn. We wish to establish a positive, safe, learning environment where students feel good about themselves and good about the information they are learning.

Type One Learning Activities

A list of first quadrant learning activities is shown in Table 2. As already mentioned, these activities seek to answer the question WHY?. A more detailed discussion of several of these activities is provided below.

1. Stories: A great way to help students understand the purpose for learning a particular concept or procedure is to share your own experiences. Stories that help students visualize the application of a concept in a professional setting are particularly effective. Experiences related to important societal issues (e.g. environment) are also very effective. We, as educators, need to develop a "story file" for use in the classroom.

2. Simulation: Provide a simulated experience for the students in order to illustrate the importance of the concept of interest. This simulation may be performed either in or out of the classroom and may range in complexity from a "thought experiment" to a complex computer simulation. For example, a computer model could be used to allow students to "observe" the response of a piece of equipment to changing operating conditions. This would be an excellent preface to instruction on the principles which govern the operation of that equipment item. After the simulation the students should be required to reflect on the experience and articulate the motivation for learning the principles of operation (e.g. safety, stability, quality control, etc.).

Table 2. FIRST QUADRANT LEARNING ACTIVITIES

Motivational Stories
Simulations
Class Discussion
Group Discussion
Journal Writing
Brainstorming
Interactive Lecture
Group Problem Solving
Formal Lecture, feeling tone
Field Trips
Role Playing
Socratic Lecture
Group Projects
Group Experiments
Subjective Tests

3. Class Discussion: Use a discussion to help the students evaluate why a topic may be important rather than simply telling them or illustrating the motivation in a story. Questions can be used effectively to stimulate such a discussion. These types of questions are typically phrased so that there is more than one "correct" response; the students should be required to make some sort of evaluation and offer an opinion on the subject.

4. Group Discussion: Introduce the topic of discussion and then divide the class into groups with the assignment to determine, for example: l) potential applications of the topic under consideration; or 2) the relationship of this topic with other material which the student has learned previously. The objective is for the students to reflect on their collective experience in order to determine the value of the new material. Group work must be performed within a specified time limit to keep students' attention. Also, each student should be held accountable for the information derived from the group work. One way to do this is to arbitrarily call upon a student to report on the results of his/her group discussion after the group work is finished.

5. Journal Writing: Have the students reflect on their own experience and record their opinion, thoughts and feelings in a journal. This task may be performed both in and out of the classroom. For example, students could be required to make a journal entry outside of class for each class period. In addition to allowing time for reflection and conceptualization, journal writing requires students to articulate their thoughts in written form. Reading of these entries can also be very enlightening for the instructor.

6. Brainstorming: The purpose of brainstorming is to generate as many alternatives or solutions as possible that address a specific task or problem. The ability to generate ideas or solutions is a critical element of engineering. It is an element however, that is frequently overlooked in our undergraduate classes. Brainstorming activities can be performed both in and out of the classroom as described in the paragraphs which follow.

In the classroom, brainstorming activities are often an excellent way to begin class. They also serve as an excellent "wake-up call" in the middle of a lecture. It is probably best to put the problem of interest on the chalkboard or screen and read it together in order to clarify the specific objective. It is important that the problem be available to the students after the initial reading as they like to refer back to it while generating solutions. Give the students a specified period of time to complete the exercise (e.g. 5 minutes). One way to brainstorm is to have the students do brainstorming in groups of two or three with one person writing down the ideas. It is often helpful to add a little competition by recognizing the group which generates the most solutions or the most creative solution. A brainstorming activity in class is a relatively simple activity which can be a lot of fun.

For out of class brainstorming activities, please refer to an excellent article by Professor Richard Felder called "On Creating Creative Engineers" [18]. This article describes several out-of-class brainstorming activities which were assigned in a junior-level course in fluid dynamics and heat transfer. Of particular interest is the creativity demonstrated in the problem statements themselves, and the procedures which were used to grade the problems. The following example is one of the problem statements:

"You are faced with the task of measuring the volumetric flow rate of a liquid in a large pipeline. The liquid is in turbulent flow, and a flow velocity profile may be assumed (so that you need only measure the fluid velocity to determine the volumetric flow rate). The line is not equipped with a built-in flow meter; however, there are taps to permit the injection or suspension of devices or substances and the withdrawal of fluid samples. The pipeline is glass and the liquid is clear. Assume that any device you want to insert in the pipe can be made leak proof if necessary, and that any technique you propose can be calibrated against known flow rates of the fluid.

Come up with as many ways as you can think of to perform the measurement that might have a chance of working. (Example: Insert a small salmon in the pipe, suspend a lure irresistible to the salmon upstream of the insertion point, and time how long it takes the fish to traverse a measured section of the pipe.) You will get one point for every five techniques you think of (no fractional points awarded), up to maximum of 10 points. Note, however: The techniques must be substantially different from one another to count. Giving me a pitot tube with 10 different manometer fluids, for example, will get you nowhere."

II. Quadrant Two

Objectives

The second quadrant is characterized by the question **WHAT**?, such as what information do I need to know to solve this problem? Learners in this quadrant are looking for the facts. Specific objectives for the quadrant include:

Provide information to the students. Traditionally, this function has been equated with the role of a teacher. Although we have emphasized the need for learning activities in each of the four quadrants, information transfer (quadrant two) remains an essential function of the engineering professor.

Organize and integrate new material. New information must be presented in a well-organized logical fashion and integrated with the material which has previously been learned.

Provide time for thinking and reflection. Type two learners process information reflectively; consequently, we must provide opportunities for them to process the information which we have presented. If we continue to provide new information without allowing time for processing, we will quickly saturate our students; obviously, information saturation leads to very low retention levels.

The principal role of the teacher in this quadrant is that of an **EXPERT** who provides information in a well-organized fashion to his/her students.

Type Two Learning Activities

A variety of activities which have been successful in quadrant two are shown in Table 3. Additional detail on a sample of these activities is provided in the discussion that follows.

Table 3. SECOND QUADRANT LEARNING ACTIVITIES

Formal Lecture, thinking tone
Lecture with Visual Aids
Lecture with Programmed Notes
Textbook Reading Assignment
Problem Solving by Instructor
Demonstrations by the Instructor
Example Problems from Textbook
Professional Meetings
Large Seminars
TV Demonstrations
Independent Research
Objective Exams
Library Searches
Gathering Data

1. Lectures: Lectures are an excellent way to efficiently transfer information from the instructor to the student. There are several comments which can be made with regards to making our lectures more effective:

Remember the 20 minute rule! As a general rule, we should never lecture for more than 20 minutes at a time without providing some sort of opportunity for students to process the information already presented. Note that information processing does not require an elaborate activity. For example, a few well-directed questions can serve as a very effective processing tool. Alternatively, a switch between activities in different quadrants (e.g. quadrants two and three) is an efficient and effective way to provide processing time. Some of the quadrant two activities discussed below (e.g. problems worked by the instructor) are designed to help the students process information.

Organize the material. It is important for us to establish how different pieces of information relate to one another and to other information previously learned. The traditional tool for this task is an outline. An alternative to an outline is a tree diagram which explicitly shows connections between subtopics and thus enhances the student's ability to visualize relationships (Figure 7). Organization is important to Type 2 learners.

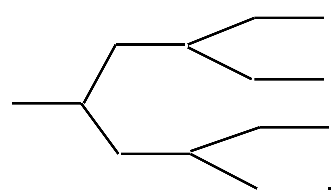


Figure 7. Schematic of a tree diagram.

Use prepared notes. It is often helpful to students if we will prepare our notes in advance and provide copies of the notes to the students. These notes need not, and probably should not, be complete to the last detail. Instead, we recommend that you leave blanks for the students to fill in information, derive simple equations, or write down definitions and/or responses to questions. In this way, we can keep their interest and attention without requiring them to write down every word. The students will then have more time to reflect on the information. Consequently, a greater percentage of what is taught is actually "caught."

Use visual aids. With today's technology we can produce high quality visuals with relatively little effort. We need to take full advantage of the available resources. However, it is possible that visual aids may have a negative influence on classroom learning if they are used improperly. For example, it is easy to move rapidly through a set of well-prepared overhead transparencies; such rapid coverage of the material will be very frustrating for the students who are trying frantically to take notes and cannot keep up. This problem can be easily resolved by providing students with a hardcopy of the visuals to which they can add brief notes as required.

2. Textbook Assignments: This is a comfortable way for Type 2 learners to gather information. Most textbooks are written by Type 2 learners and are therefore well suited to the needs of the Type 2 student.

3. Problems Worked by the Instructor: Type two learners process information reflectively, or by "watching." Example problems worked by an instructor provide the opportunity for these students to process the material (make it a part of themselves). The learners in this quadrant are concerned about what we (the experts) think and how we approach problems. They want a model which they can follow.

4. Demonstrations Performed by the Instructor: Demonstrations performed by the instructor also provide the students with an opportunity to watch, reflect, and process.

5. Example Problems from Textbook: Assign students to work an example problem from their textbook. In this way they can process the information by following ("watching") an established solution procedure. It is often useful to have them write down the motivation behind each step in the solution process, in addition to completing the solution itself.

III. Quadrant Three

Objectives

The third quadrant is characterized by the question **HOW**? (i.e. How does this work?). Learners in this quadrant are "doers" who prefer to process information by applying it; they are the type of people who toss aside the instruction manual and brave the new computer program themselves. In this quadrant we help the Type 3 learners, as well as our other students, to gain experience with the material we have taught. Specific objectives include:

Provide Opportunity for Students to Apply the Material. This application needs to take place both inside and outside of the classroom. In-class application provides a wonderful opportunity for us to guide our students through critical steps in the problem solving process.

Help Students to Develop Problem-Solving Patterns. We need to establish a "working nucleus" of problem solving techniques that can be interconnected with other experience and open-ended situations later.

Establish a Safe Learning Environment. New application inevitably includes the potential to fail. Ideally, we would like to create a learning environment which would allow students to fail safely. Note that this concept is not a natural aspect of our present academic system; failure usually translates into a low test score or points off on a homework assignment, etc.

The teacher's role in this quadrant is that of a **COACH**. In quadrant three we seek to provide guided experience for our students. In general, we should "explore the rule rather than the exception" as we seek to establish problem-solving techniques. Processing takes place through the formation of problem solving patterns. The value of the concepts learned is determined by their applicability.

Type Three Learning Activities

Table 4 gives a summary of third quadrant activities. Additional details and suggestions for several of these are provided in the paragraphs that follow.

Table 4. THIRD QUADRANT LEARNING ACTIVITIES

Example Problems Worked by Students
Homework Problems
Guided Labs
Computer Simulations
Field Trips
Objective Exams
Laboratory Test
Individual Reports
Computer-Aided Instruction
Lectures with Demonstrations

1. *Example Problems in Class:* Problems should be worked by the student to be consistent with the objectives of this quadrant. There are several different ways to effectively implement this activity including:

Have students work problems at the blackboard. This activity is best suited for small- to medium-sized classes. A single student could be called upon to work a problem for the class. Alternatively, you may want to divide the class in groups and have one student from each group working simultaneously on different blackboards; the teacher would then be free to move from board to board in order to coach the students.

Assign students to work individually on a problem in class. This would typically be an example problem which illustrates the lecture material. The teacher is available to coach individual students. It is often advantageous to request students who are stuck to raise their hands. In a large class, the teacher may want to use other students to help with the coaching.

Assign groups of students to work together on a problem. An excellent way to initiate group work is to have the students work individually on a problem for a period of time before dividing into pairs. The pairs then continue working on the problem (until they agree or a time limit is reached) before combining with another group to form a group of four, etc. In this fashion the students coach each other through the problem. This activity can be performed with any size class. The teacher is free to observe the class and offer assistance as required.

2. Homework Problems: This is the traditional way of providing students with application experience. Single-answer problems which establish problem-solving patterns are especially useful at this stage in the cycle.

3. Guided Labs: The guided labs are intended to help students experience the material learned in class. The physics laboratory experiments that many of us performed as part of our first college physics course are a good example of a guided laboratory experience. Guided labs may be integrated with classroom "lectures" or grouped together at the end of a course. For example, we have our process control students go to the lab and "tune a loop" after learning the principles in class. Also, after teaching our students about flooding in a packed column, we take them into the unit operations laboratory and let them flood a column for themselves.

In order for guided labs to be successful, it is essential that they work properly. Otherwise, the lab will fail to provide the desired experience and the students will become frustrated. Rather than reinforcing the important concepts, students will conclude that the principles which they have been taught do not apply to real situations. These labs should not address open-ended problems.

4. Simulations: Often it is not feasible to provide students with a "hands on" experience of the material we are teaching. The next best alternative is a simulated experience. Sophisticated computer simulations of many different types of engineering equipment and/or structures are readily available. These simulators allow students to "observe" the effect of changing variables (e.g. temperature, composition, stress, etc.) on equipment operation. For example, a student could use a model to apply a stress to a structure in order to observe the response of the structure. Many of these simulators now come with graphical interfaces which greatly increase their utility for student instruction.

IV. Quadrant Four

Objectives

The fourth quadrant is characterized by the question **WHAT IF**?. This last quadrant is one of *self-discovery* where the students seek to apply the material and information to their own lives. This type of application is different from the guided experience provided in quadrant three. In quadrant three we establish problem solving procedures; in quadrant four the students apply those procedures to new situations in order to solve "real" problems. The WHAT IF? question can alternately be expressed as [2]:

What can this become?

How can I apply this?
What if the problem were different-
how might I apply these concepts?

Note that the student is asking himself/herself these questions, consistent with the concept of self discovery. Objectives for this quadrant include:

Provide Opportunity for Self Discovery. As instructors, it is our responsibility to provide opportunities for our students to discover material for themselves. We should encourage them to be creative and then reward their creativity.

Provide Opportunities for Students to Share Discoveries. One of the important elements of self discovery is the excitement of sharing your findings with others.

Evaluate Performance. We need to evaluate the performance of our students and provide remedial action as required.

Activity in this quadrant is focused on the student rather than the teacher. In other words, the primary role of the teacher in this quadrant is not to play the primary role. The teacher should observe the performance of students, evaluate their abilities, and provide remedial action as required. Hence, the principal role of the teacher is that of **EVALUATOR/REMEDIATOR**.

Fourth quadrant activities are typically lacking in our engineering classrooms, especially in lower division courses. The result of this deficiency is seen in graduates who are ill-prepared to creatively handle open-ended problems. Hence, there has been a call by engineering educators for more "design" in the curriculum. In our opinion, what is really needed is a consistent effort to traverse the complete learning cycle.

Type Four Learning Activities

Type 4 learning activities are shown in Table 5. Several of these activities are discussed in more detail in the text that follows.

Table 5. FOURTH QUADRANT LEARNING ACTIVITIES

Open-Ended Problems
Open-ended Laboratories
Student Prepared Problems
Field Trips
Student Presentations
Semester Long Design Projects
Socratic Questioning
Group Discussion
Student Lectures
Brainstorming
Role Playing
Subjective Exams
Training
Think Tanks
Quality Circles
Simulations
Group Problem Solving
Group Projects/Reports

1. Open-Ended Problems: An open-ended problem is one that does not have a preconceived single-answer solution. For example, the design of a chemical plant must balance the desire to maximize profit, maximize safety, and minimize environmental damage. The net result is a large number of possible solutions with different trade-offs. It is important to expose students to this type of problem throughout the curriculum. If this is not done, they may not develop the skills needed to adequately perform the important function of engineering design. Use of the learning cycle, including quadrant 4 activities such as open-ended problems, will help students to develop the skills necessary to solve real-life problems.

Although open-ended problems include large semester-long or year-long design projects, they are not restricted to such. Also, it is not always necessary to solve the complete problem. Felder assigned open-ended problems to students who were required to state what they needed to know to solve the problem and how they might go about obtaining the needed information [18]. One of the authors requires students to synthesize a flow sheet for a chemical process based on qualitative arguments only, without performing any calculations. The size of open-ended problems may also be limited by reducing the scope to focus on a particular piece of equipment and predict, for example, the effect of changing reactor operating conditions on other potential units in the process, etc.

Open-ended problems also fit very nicely into our lower division courses. Beginning engineers are typically taught a variety of computation tools such as spreadsheets, equation solvers, and a programming language. Once they have learned the tools, students may be asked to solve a particular problem using the tool which, in their opinion, is best suited to the task. In this case, we require them to both solve the problem and to justify their method of solution. The addition of a "what if" question also increases the open-endedness of the problem as discussed previously. Students in a beginning mass balance class could be given open-ended questions which require them to anticipate the potential hazard of chemicals involved in a process, or to hypothesize on how the "black boxes" in the flowchart accomplish the desired reaction or separation.

2. Open-Ended Laboratories: Frequently, laboratory experiments are designed to provide students with a carefully guided experience of data collection and solution for some parameter such as a heat transfer coefficient. While these kinds of laboratory experiences satisfy one type of learner, they do not meet the needs of the Type 4 learner. There are several things that we can do to provide a different experience for our students in the laboratory. First, formulation of an open-ended problem statement rather than the use of a straight-forward application question helps provide a better training experience. A problem statement could be changed from "Determine the heat transfer coefficients of these three rods" to "How can we improve the heat transfer characteristics of these rods?"

A second way to enhance the learning experience in the laboratory is to involve students in the problem formulation. Students can be asked to review a previous laboratory report concerning the apparatus that they are about to use. They can then be asked to design their own experiments to solve a problem of their choosing with the use of that particular apparatus. The problem statement should be reviewed and approved by the instructor before the actual experiment is performed. This allows the students to synthesize material from a previous report and to use their creative skills to generate a new problem statement.

A third way to use an open-ended laboratory is to couple it with a previous laboratory that was not open-ended. In our process control class students are asked to perform a controller-tuning experiment in which the procedure has been worked out previously by a teaching assistant. The procedure is designed to be without 'bugs' so the students are provided (hopefully!) with a successful experience in the laboratory. After completing this experiment, the students are asked to tune on their own a controller involving a different control loop. As part of this, they are asked to use more than one of the techniques previously discussed in class. Based on feedback from students, it appears that this open-ended exercise has helped to crystallize in the minds of many students the concept of controller tuning, thus accomplishing one of the main goals of the process control class.

3. Student-Prepared Problems: Rather than simply relying on instructor-formulated problems in a formal-lecture course, instructors could help students' creative skills by asking them to provide problems and solutions to those problems. This allows the students to synthesize the knowledge from a course and often generates a much higher level of thinking than the thinking associated with solving the normal set of application problems that instructors generally use. We have used this technique on final exams where the students were asked to formulate a problem and solve it as part of the exam. We have also had the students make up questions prior to a mid-term exam as part of their homework, and then rewarded the students with the best questions by using them on the exam. Felder has also discussed the use of student prepared problems as a vehicle for enhancing student creativity and learning [18].

4. Field Trips: Field trips to industrial settings provide a unique opportunity to relate to students the transition from theory to practice. One of the authors takes his class to the university physical plant. The physical plant uses a computer control system similar to that which exists in our unit operations laboratory and which is used in the process control class. Students can see the theory put into actual practice. When they return to the class and begin to design and tune controllers on paper, it is easier for them to picture what could be happening in the actual process. In another class, the students get a tour of the physical plant from the burners on the ground floor to the stacks on the top floor. When they return to the class and begin a discussion of lost work and entropy, they can relate these concepts to the increasing temperatures as they moved up through the physical plant layout. They also can get a better feel for efficiency, waste, and environmental concerns.

5. Student Presentations: When students are asked to present material in class, the process that is undergone to accomplish the task enables them to synthesize the material and really sharpen their understanding of it. The presentation can be anything from simply a homework problem solution to a final report on a term project. Not all students will feel comfortable presenting information in class. For that reason, this activity should be carefully planned. Those students that do not feel comfortable should be well coached and prepared for their task.

6. Semester-Long Design Projects: These are longer problems (e.g. one semester or a full calendar year) which require students to apply the concepts they have learned to solve "real-life" problems of formidable size. Some universities have successfully integrated their design projects with industry so that the students are solving problems of current industrial significance [19].

7. Classroom Discussion: Use a "What if?" question to create a new situation for your students to solve. Call on students to respond to the question. Another alternative is to have all of the students write down a response to the question. These responses may then be shared with the class or group.

8. Group Work: Use of groups is an excellent way for students to share ideas learned from "self-discovery." It is also useful to have students work in a group to solve a problem together. Group problem solving may be done both in and out of the classroom. Problems should be open-ended and provide an opportunity for creativity. You may have all the groups working on the same problem or prepare separate problems for each group. Use of oral presentations is one way to share the information learned from group work with the rest of the class.

ENGINEERING DESIGN AND THE KOLB LEARNING CYCLE

Design is a creative, open-ended activity which typically leads to a large number of possible solutions. It requires engineers to generate and synthesize ideas into workable solutions, analyze the advantages and disadvantages of a particular solution, and evaluate the relative merits of alternate options or solutions. It follows that, in a very real sense, we are teaching design when we teach students how to synthesize, analyze, and evaluate, which are all elements of the Learning Cycle [20].

In engineering design activities, students apply the concepts and procedures which they have learned to new situations in order to solve "real" problems. Engineering design activities are typically lacking in lower division courses. It is our belief that the incorporation of design across the curriculum is a natural consequence of completing the learning cycle for every concept which we teach. As we consistently traverse the learning cycle, our students will be learning and practicing design. In other words, the basic problem is not that we are failing to teach the particular subject of design, it is that we are failing to properly teach by not including activities from all four quadrants. In particular, we fail to address the skills of synthesis, analysis, and evaluation, and to provide the self discovery experiences which form an integral part of the Learning Cycle.

SUMMARY OF INSTRUCTIONAL ACTIVITIES

A summary of the objectives and the activities corresponding to each of the four quadrants is provided in Figures 8 and 9, respectively. These figures are patterned after McCarthy's 4MAT System [2] and represent a resource that can be easily referenced during lesson preparation.

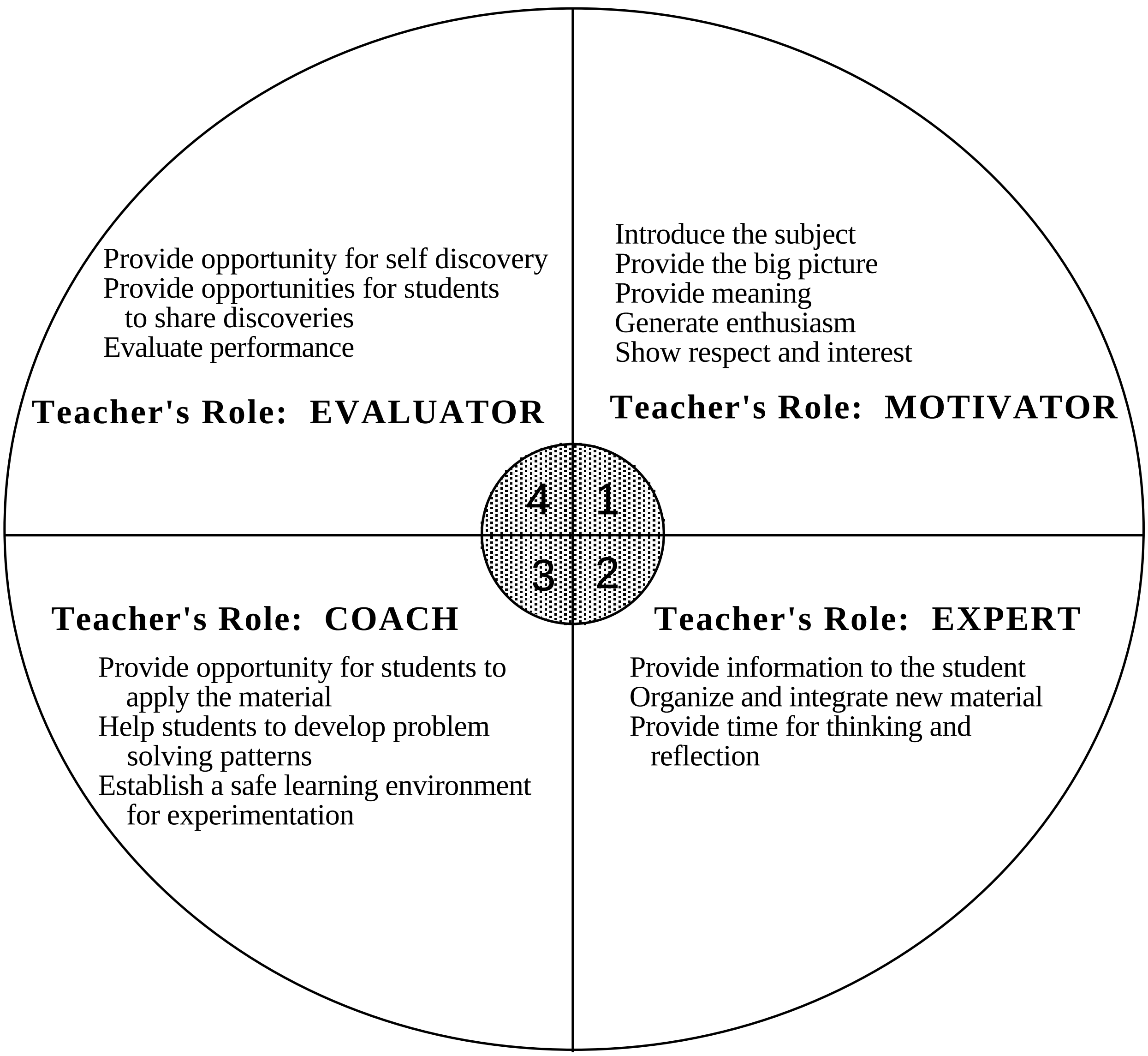


Figure 8. Summary of objectives for each quadrant in the Learning Cycle.

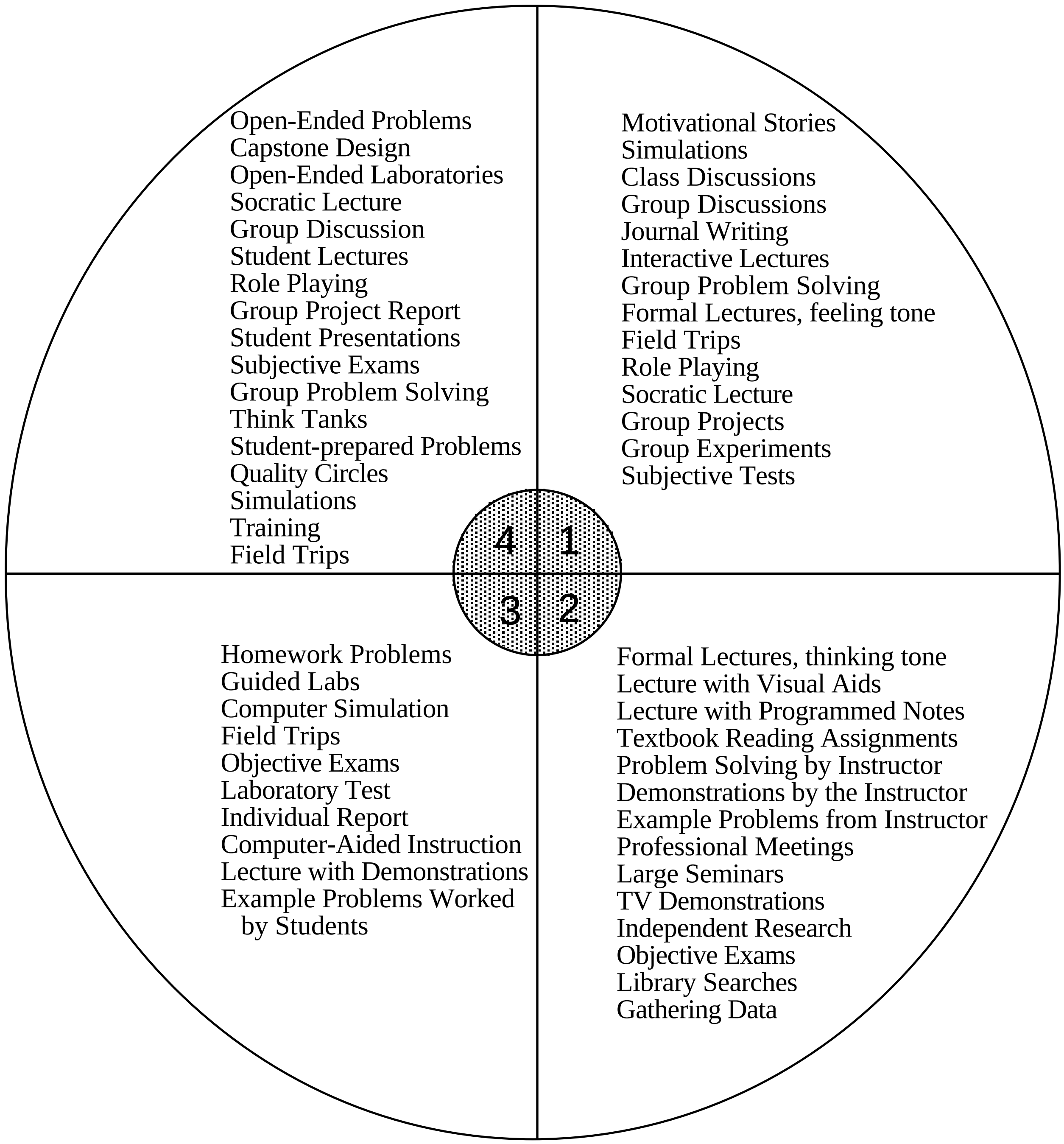


Figure 9. Summary of learning activities for each quadrant of the Learning Cycle.

2. QUESTIONING AND THE KOLB LEARNING CYCLE

INTRODUCTION

In the material that follows, we examine questions applicable to each of the four quadrants of the Kolb cycle by relating the quadrants to the taxonomy of cognitive objectives developed by Bloom [13]. Bloom's objectives were grouped in the following six divisions: *knowledge; comprehension; application; analysis; synthesis; and evaluation* (see Table 6). Bloom ordered these divisions into levels of thinking and learning beginning with the lowest level of *knowledge* and ending with the highest level of *evaluation*. Note that the top three levels of analysis, synthesis, and evaluation can be referred to as higher level learning and correspond to the skills needed for engineering design as discussed in the previous sub-section. The six divisions have been used to define six different types of questions [21]. In this subsection, we describe the six types of questions and relate each of them to a particular quadrant of the learning cycle. Example questions are also provided for each of the quadrants.

THE KOLB LEARNING CYCLE AND BLOOM'S TAXONOMY

I. Quadrant One

The objective of this quadrant is to establish the motivation for learning the material at hand and to develop an understanding of how the material fits into the "big picture." As previously mentioned, the quadrant is characterized by the question "Why?" (e.g. Why am I learning this? or Why is this important to me?). First quadrant questions should assess the students' understanding of the 'Why?' question as used in this quadrant, as well as their abilities to respond to the question.

A type of question which is well suited to the first quadrant is an **evaluation question**. An evaluation question requires the student to make a judgment on the value or merit of the subject under consideration. Judgment or evaluation in this quadrant should be performed by the individual student based on his/her own standard as opposed to a dictated standard determined on logic alone. In other words, the objective is to have the students make the judgment and express why they feel the material is or isn't important.

We do not want them to simply parrot back a list of reasons which were provided by the instructor. All too frequently students are answering questions like the following:

- What does the professor think is important?
- How would the professor answer this question?
- What does the professor want me to say?

instead of questions like:

- How is this information useful?
- Why is this problem important to solve?
- Is this the best solution to the problem?

Table 6. Categories in Bloom's Taxonomy of Educational Objectives, Cognitive Domain.

1.	Knowledge	The remembering of previously learned material. Represents lowest level of learning outcome.
		1.10 Knowledge of specifics
		1.11 Knowledge of terminology
		1.12 Knowledge of specific facts
	1.2 Knowledge of ways and means of dealing with specifics	
		1.21 Knowledge of conventions
		1.22 Knowledge of trends and sequences
		1.23 Knowledge of classifications and categories
		1.24 Knowledge of criteria
		1.25 Knowledge of methodology
	1.3 Knowledge of the universals and abstractions in a field	
		1.31 Knowledge of principles and generalizations
		1.32 Knowledge of theories and structure
2.	Comprehension	The ability to grasp the meaning of material. Represents the lowest level of understanding.
3.	Application	The ability to use learned material in new and concrete situations. Represents a higher level of understanding than comprehension.
4.	Analysis	The ability to break down material into its component parts so that its structure may be understood. Represents a higher level than application, because understanding of both content and structural form are required.
5.	Synthesis	The ability to put parts together to form a new whole. Creative behaviors are stressed, with major emphasis on the formulation of new patterns or structures.
6.	Evaluation	The ability to judge the value of material for a given purpose. The highest level of intellectual activity, because elements of all other categories are contained, plus conscious value judgments based on clearly defined criteria.

Questions which require students to make judgments based on their own experience and intuition naturally lead to a multiplicity of responses. We must be willing to accept different responses as being equally valid and evaluate performance on the quality of thought rather than the extent to which a response agrees with our own response to the question.

Some examples of evaluation questions for quadrant 1 are given below:

- What is your opinion about nuclear energy as a viable energy source for the U.S. in the future?
- Which solution to the problem do you prefer? Why? (Justify your response.)
- In your opinion, is it more important for an engineer to be environmentally responsible or economically productive? Why?
- In your opinion, what factors may affect the design and operation of a chemical reactor and why are they important?

II. Quadrant Two

Quadrant 2 is the information quadrant. This is where we, as educators, provide information to the students. In addition, activities in Quadrant 2 should include time for thinking and reflection in order to permit students to process the new information. Quadrant 2 questions should assess the students' knowledge of the material presented. Assessment of the students' ability to assimilate new ideas and thoughts should also be included in this quadrant.

There are three types of questions, based on three of the six divisions of Bloom's taxonomy, that are applicable to this quadrant. The first type of question is a **knowledge question**. Knowledge questions require students to simply recall information which they have seen or heard. This type of question does not require students to understand or use the information; therefore, these questions test the ability of the students to remember, not to think. There are several different types of knowledge which the students may be requested to recall, including knowledge of [13]:

Terminology
Specific Facts
Conventions
Trends and Sequences
Classifications and Categories
Criteria
Methodology
Principles and Generalizations
Theories and Structures

The response to a knowledge question may vary in complexity from a single word to a lengthy recitation of a sophisticated theory. Still, all that is required is proper recall of the desired information. Examples of knowledge questions are provided below.

- Define discounted cash flow rate of return.
- Who made the first discovery of a superconductor? What was the transition temperature of the first superconductor?
- When did Newton develop his ideas about mass and acceleration?

The second type of question relevant to this quadrant is a **comprehension question**. Comprehension questions require students to know and make use of information in its immediate context, without relating it to other material or recognizing its fullest implications [13]. Comprehension may be evaluated by requiring students to reorder, rearrange, explain, or summarize the information which they have learned. For example, they might be required to recall facts by organizing them in a particular order, or to describe material in their own words. The ability of students to translate written material to symbolic mathematical statements is another aspect of comprehension. Comprehension also includes comparison of information and extrapolation of trends based on the original information. Some examples of comprehension questions are provided below.

- Describe what happened at Chernobyl.
- Compare the internal rate of return with the external rate of return.
- Arrange the chemicals below according to their relative volatility with the most volatile component first.

The third type of question is an **analysis question**. Analysis questions may include one or more of the following elements [13,21].

1. Identification of causes and motives
2. Identification and/or explanation of connections and interactions between different aspects of a problem (e.g. consistency of hypotheses with experimental data or observations)
3. Identification of the constituent parts of a problem (e.g. the breakdown of a problem into fundamental parts)
4. Recognition of the general concepts or principles which explain a specific set of data (inductive)
5. Identification of data or specific examples to support a generalization or inference (deductive)

Some examples of analysis questions are:

- The author states that a temperature difference can cause movement of mass. What evidence do you have from your experience that would support that statement?
- Why did the bridge fail?
- Do the following data support your hypothesis? Why or why not?
- The amount of steam production decreased when fuel was added to the boiler. Why? What could have caused this behavior?

It is apparent from the above examples that analysis questions may (and often do) begin with the word 'why'. This type of question should not be confused with the Why? question which characterizes Quadrant 1. The question beginning with the word 'why' in Quadrant 2 seeks an objective analysis (Why did the bridge fail?) as opposed to the value judgment of Quadrant 1 (Why is it important for me to understand free body diagrams?). Note that both of these types of questions require students to think at a higher level than do knowledge questions or comprehension questions.

III. Quadrant Three

The objective of this quadrant is to help students to develop problem-solving patterns or skills, and to give them opportunities to apply those skills. In other words, the third quadrant is application-oriented. Consequently, third quadrant questions should focus on the ability of students to apply the problem solving skills which they have learned.

Application questions are common on engineering exams. These are single answer questions which require students to apply the "abstract" concepts, rules, theories and/or techniques which they have learned to concrete problems. Application questions represent the most frequently used type of question in both engineering and science. Two application questions are given below, (although each engineering educator undoubtedly has numerous examples of this type of question):

- Calculate the heat transfer coefficient given the appropriate data.
- Determine the equivalent resistance for the circuit shown below.

IV. Quadrant 4

This is the self discovery quadrant where students seek to apply the material and information which they have learned to their own lives or to simulated "real life" experiences. Much of what is commonly referred to as "engineering design" falls into this quadrant as discussed earlier. Fourth quadrant questions should assess the ability of students to solve complex problems creatively. Such problems are usually open-ended, involving multiple alternatives.

One type of question which fits well into this quadrant is a **synthesis question**. Bloom defines synthesis as "the putting together of elements and parts so as to form a whole" [13]. An open-ended design problem is an excellent example of a synthesis question. Note that not all design problems need to be month-long, super projects. For example, we have required students on an exam to synthesize a flowsheet based on qualitative arguments without performing the detailed calculations necessary to size and cost each piece of equipment.

Open-ended design problems are not the only type of synthesis questions. Questions which require the development of a plan or proposal to perform a particular task also belong in the synthesis category. In addition, questions which require students to make predictions based on their experience and knowledge are also synthesis questions. Several examples of synthesis questions are:

- What would happen if the reboiler on a distillation column suddenly stopped working? Why?
- What will happen if we change the material of the wall so that the R factor is increased to 21 from 15?
- What do you predict would happen to the coal industry if global warming is proven to be a fact?
- How can we improve the performance of the heat exchanger?
- Can you think of a way to change the design of the reactor so that we could get better conversion of product Z?
- Develop a qualitative flowsheet for a chemical process to produce benzene from toluene.

Questions which require predictions can be a lot of fun in the classroom, especially if the answer is not obvious (or unknown, for that matter). You may want to ask the question to individuals first, and then have them form pairs to see if they can reach a consensus. The group size could then be increased to four, etc., depending on time and interest.

Another variation of a synthesis question is a "What if" question. For example, one assignment that is given early in the semester in our sophomore computing class is to calculate the efficiency of a gas absorption column used to clean contaminants from a gas stream. Although the students will not learn the theory to describe this equipment until their senior year, the basic concepts of operation are well within their grasp. The students are first asked to calculate the efficiency for a well-defined set of conditions. This well-defined calculation is followed by a "What if" question which asks them to predict (qualitatively) the change in column performance as the liquid flow is increased or decreased, or as the number of trays in the column is increased. They are then asked to check their predictions with use of the computer code they just wrote and to explain why the observed changes occurred. Practical limitations are also important since, for example, the liquid flow rate cannot be increased indefinitely. The response of these students to this exercise has been positive. They enjoy solving a "real life" problem and appreciate the environmental application.

The increasing use of equation solvers and spreadsheets presents a wonderful opportunity for the use of "What if" questions. A student or group of students who has worked through a complicated problem with either of these tools can easily and quickly rework the problem for a variety of different parameters. In fact, they can even graph the results to help them visualize trends and interactions. "What if" analysis should be a routine part of problems which use these powerful tools.

SUMMARY OF QUESTIONING AND THE KOLB LEARNING CYCLE

We have examined the use of several different types of questions, based on Bloom's taxonomy of cognitive objectives, which pertain to each of the four quadrants of the Kolb learning cycle. Figure 10 presents a summary of the types of questions as they relate to the Learning Cycle. Each type of question is used to evaluate a different aspect of student learning. A combination of questions which address the different learning types provides a measure of the ability of students to think and learn in a variety of ways. Of particular importance are analysis, synthesis, and evaluation questions which require students to think at a higher level.

Numerous additional examples could be given. The key point, however, is that we must use questions which require students to use the higher-level cognitive skills. Use of higher-level questions can make a difference as recognized by a student who recently told one of the authors that he liked his teaching style because it required him to think.

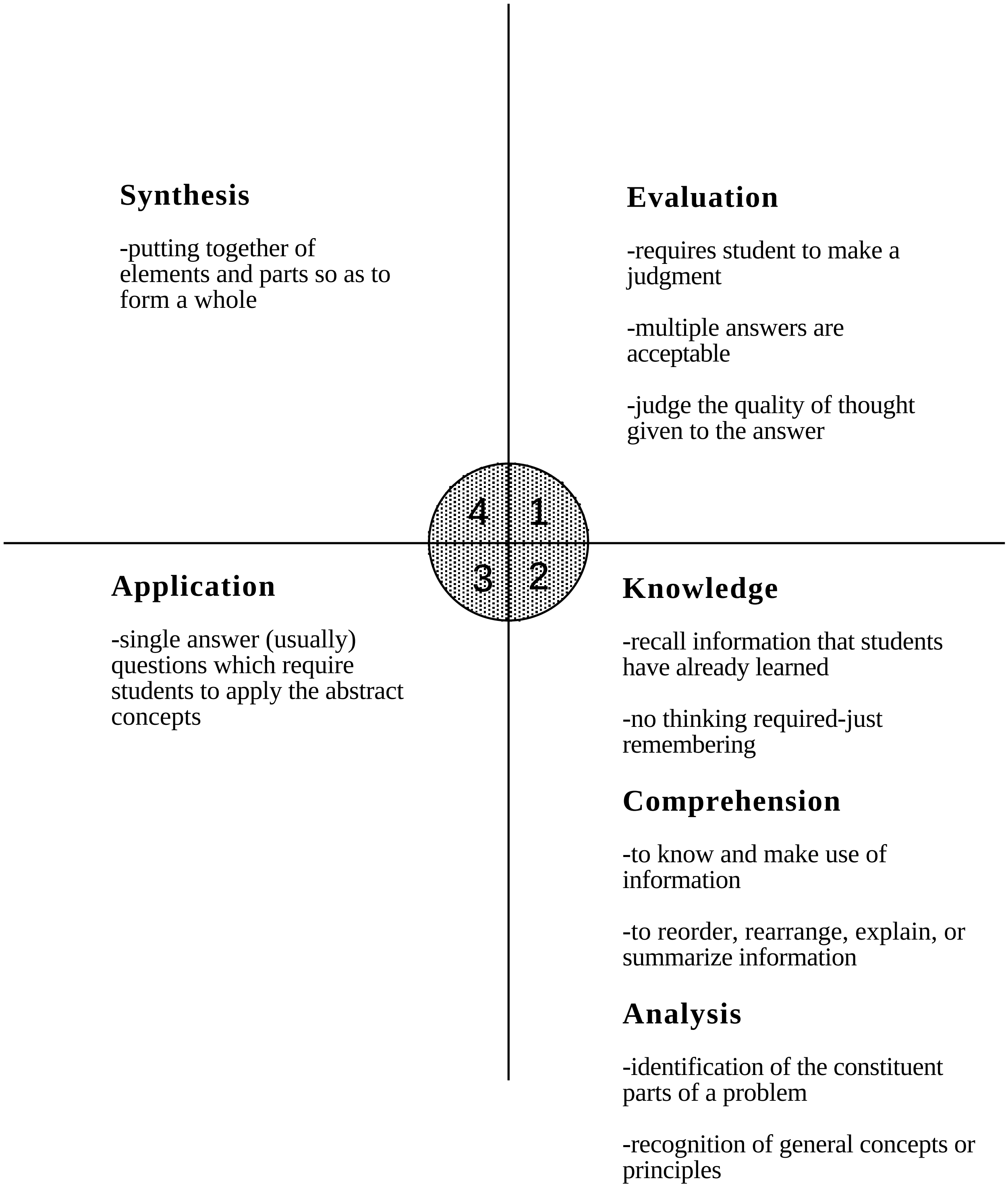


Figure 10. Summary of questioning activities for each quadrant of the Learning Cycle.

We would encourage educators to evaluate the types of questions that they are using in the classroom, on homework assignments, and on exams. This can be done, for example, by tape recording classroom lectures and then classifying the types of questions according to Bloom's taxonomy.

Engineering exams represent an area of particular concern as they tend to be noticeably deficient in higher-level questions as noted by Stice and others [7,8]. As engineering educators, we should use a variety of different types and levels of questions on our exams. It is especially important to include analysis, synthesis, and evaluation questions which require students to think at a higher-level in addition to questions which address knowledge, comprehension, and/or application. However, higher-level questions are more difficult to use because they require significantly more time to write and to grade. Another difficulty with the use of these questions is that students appear less willing to accept the teacher's evaluation of their performance on such questions. One way to help alleviate this problem is to post examples of high quality responses given by other students in the class, so that students have a standard on which to base their judgment. In spite of the difficulties associated with their use, higher-level questions are important enough to be worth the extra effort. Our students need to learn to think, to be given opportunities to practice and refine their thinking skills, and to be evaluated on their ability to analyze, synthesize, and make evaluations.

Questions can also be used as a basis for classroom discussion in place of a traditional lecture. For instance, in a recent process control class, one of the authors had the class consider a typical industrial problem which involved trouble-shooting a control loop. As the class began to discuss the possible problems and solutions, higher-level questioning techniques were used to guide their thinking and analysis of the problem. The resulting questioning and discussion successfully substituted for a standard lecture on the same material which had been given in previous years.

It is essential to cultivate a positive atmosphere in the classroom for such questioning to be successful. Students must feel free to respond without fear of ridicule or criticism. Large classes present some unique challenges in this regard. In order to alleviate some of the stress related to answering a question in a large class, one teacher uses a "question of three" policy. This is an implicit policy where it is understood that whenever the instructor calls upon an individual to respond, that individual is free to confer with the students on either side if he/she does not know the answer.

3. WRITING ACROSS THE CURRICULUM AND THE KOLB LEARNING CYCLE

INTRODUCTION

The movement known as Writing Across the Curriculum (WAC) emphasizes writing in all disciplines, not just in English composition or technical communications classes. The WAC movement has as its basis the belief that writing is a means to think and to learn [22-27]. As such, writing can be used to help students learn and discover, independent of the particular subject matter. Therefore, writing-to-learn assignments can be used in engineering classes to enhance the quality of engineering education.

The use of WAC activities in the engineering classroom has been previously discussed [28]. The purpose of this subsection is to relate these activities to the Learning Cycle described in this monograph. The subsection begins with a brief review of instructional writing activities. Specific WAC activities are then related to educational objectives in each of the four basic quadrants of the cycle, and examples of activities are provided [29].

WRITING ASSIGNMENTS

The WAC movement has generated a variety of writing activities that can be used to help students learn. Several of these activities are described below [28,30-31].

- freewriting - timed-unstructured writing for the self. It can be focused on a particular issue or question.
- brainstorming - the generation of as many alternatives or solutions as possible that address a specific task or problem.
- summaries - usually a brief in-class writing at the beginning or end of class to summarize what one has learned and to bring to light further questions.
- personal reactions to course content - designed to express concerns about the course. This assignment can give feedback to the instructor about aspects of the course, such as difficulty of material.
- formulating questions - an activity to clarify information and to generate study questions and exam questions.
- sharing spontaneous writing - small discussion groups based on spontaneous in-class expressive writing assignments. This is meant to enlighten students about their strengths and weaknesses or to establish a team spirit among the students.
- peer reviews - small groups evaluating each other's papers to help improve the papers. Comments may be verbal or written and may be based on a criteria sheet.
- group written papers - students collaborating to write a paper together.

Usually students in a group all get the same grade and are responsible for each other's performance. This assignment helps prepare students for collaborative work in industry. As an added bonus, the instructor has fewer papers to grade!

- strategy notebooks - source books for keeping track of and describing methods used to solve engineering or math problems. Some examples of methods would be induction, deduction, substitution, and reduction.

- learning logs - a regular record of ideas, thoughts, questions about lectures and assignments, and data. Students can consider such questions as: What was done? What was learned? What was interesting? What questions remain?

- case studies or simulations - realistic communications problems for students to solve. Students must analyze purpose and audience and adapt information to the needs of various audiences. They take on different roles other than the role of the student.

- solving the "What if?" formula - Students are given a "What if?" question based on material just covered and they write to create something new based on what they have learned. For example, at the end of a chemical engineering laboratory course, the instructor may ask students to use their knowledge of current experiments to design a new experiment. The question might be: What if we needed to add a new experiment for mass transfer but had to work within certain constraints?

- visualization techniques, such as mapping and trees - a visual representation outlining the relationship of ideas. An example of mapping is the use of a series of circles and spokes to depict the relationship of subtopics to a particular main idea.

WRITING THROUGH THE CYCLE

The previous paragraphs discussed several types of writing activities typically associated with Writing Across the Curriculum. The following paragraphs will focus on the use of writing activities with the Learning Cycle as a pattern or model for teaching [29]. Educational objectives and writing activities consistent with the corresponding learning preference are identified for each quadrant.

I. Quadrant One

Objectives

The objective of this quadrant is to establish motivation for learning the material at hand, and an understanding of how the material fits into the big picture. As mentioned previously, this quadrant is characterized by the question "Why?" as in Why am I learning this? or Why is this important to me?. This quadrant may also be referred to as the "feeling quadrant". Activities which allow students to express their feelings and opinions are relevant here.

Writing Activities

1. Freewriting: Freewriting is an excellent activity for use in this quadrant. One use of a freewrite might be to have students reflect and write about their own experience related to a particular subject. For example, if you were introducing a lecture on polymers, you might ask students to write about the effect of polymeric materials on our standard of living, or to identify (in writing) as many polymeric materials found in their home as possible. If the students have not had experience with the subject under consideration, you may want to have them respond to a question like "How might ____(subject)____ be important for a practicing engineer?" Short writing assignments such as these are an excellent way to introduce a new subject, put the material into perspective, and generate class discussion.

Another type of freewriting exercise which is applicable to this quadrant is one in which students are asked to judge the value or merit of the subject under consideration, particularly if it relates to human welfare. For example, students may be asked to write a response to a question like "What is the most critical energy issue facing the United States today (justify your response)?" Questions which require evaluation fall into the highest level of Bloom's taxonomy and are often overlooked in our engineering courses [13,21].

2. Personal reactions to course content: Personal reactions to course content involve a brief written evaluation of the course from the students. One way to do this is to have students respond to questions such as:

What do you like about the course?
What do you dislike about the course?
What suggestions do you have for improvement of the course?

The "return on investment" for this activity is very high. Students with Type 1 learning preferences like to feel that the instructor cares about them as individuals and about their feelings. This type of activity sends the message to the students that the instructor cares in addition to providing excellent (and sometimes comical) feedback for use in making midcourse corrections.

3. Sharing of spontaneous writing: Sharing of spontaneous writing allows students to become personally involved with other members of a small discussion group. Students need to learn to listen and share ideas, as well as to accept constructive criticism from their classmates.

4. Peer review: A peer review is an activity where students are asked to evaluate each other's papers to help improve the quality of the papers. Again, the students are personally involved, making judgments, and helping each other.

5. Group writing assignments: Group writing assignments (where three or four students work on one paper and all earn the same grade) are especially good for Type 1 learners because Type 1's thrive on working harmoniously rather than competitively with others.

6. Brainstorming exercises: Brainstorming exercises represent another writing activity applicable to quadrant 1. The purpose of brainstorming is to address a specific task or problem by generating as many alternatives or solutions in writing as possible. These activities can be performed both in and out of the classroom as described in sub-section 1 earlier in this section.

II. Quadrant Two

Objectives

Quadrant 2 is the "information quadrant." The principal focus of this quadrant is the transfer and organization of information. It is characterized by the question "What?" as in "What do I need to know?". Individuals with this learning preference like to integrate new knowledge and observations into what is known. Writing activities in this quadrant should focus on analyzing information and collecting data.

Writing Activities

1. Summaries: Summaries represent a form of comprehension exercise where students reflect on and write about information presented in class, at the end of a textbook chapter, etc. It is often useful to have students identify areas or issues which are unclear as they write their summary.

2. Freewriting: Two types of freewriting exercises applicable to this quadrant are comprehension and analysis activities. A comprehension freewrite addresses understanding of the material at hand by asking students to express an idea or concept in their own words; reorder, rearrange, or explain information; or compare information in its immediate context. For example, a student might be asked to describe the first and second laws of thermodynamics in their own words so that they can be understood by a non-technical person. A student might also be asked to compare different methods for accomplishing the same task by responding to a question such as "Compare the internal rate of return with the external rate of return for evaluating the profitability of an investment."

An analysis freewrite is designed to have students use higher level thought processes to analyze a particular problem or situation. Analysis includes identification of motives or causes; explanation of connections or interactions between different aspects of a problem; the breakdown of a problem into its fundamental parts; recognition of general concepts which explain a specific set of data (inductive reasoning); and identification of specific data or examples to support a generalization (deductive reasoning). Often laboratory reports are good examples of analysis freewrites. The following example is taken from a write-up of a process control experiment: "Explain how the data you generated from the level loop support the generalization that the derivative mode of a proportional-integral-derivative controller is not often used for level control."

3. Mapping and tree diagrams: Mapping and tree diagrams are useful techniques for helping students visualize and organize data. These techniques explicitly show connections between subtopics and enhance the students' ability to recognize relationships. This activity is appropriate for both in and out of class assignments.

III. Quadrant Three

Objectives

Quadrant 3 is the "application quadrant." It is characterized by the question, "How?" as in "How does this work?". The principal educational objective in this quadrant is to help students develop problem-solving patterns or skills, and to give them an opportunity to apply those skills. Writing assignments in this quadrant should require students to think strategically, focus on skill development, and integrate theory and practice.

Writing Activities

1. Strategy notebooks: Strategy notebooks allow students to keep track of and describe methods or patterns for solving engineering problems. The focus of these notebooks is on strategies for using theory and concepts to perform useful tasks, consistent with the objectives of this quadrant. Such notebooks could be used in conjunction with a class or a laboratory. It is usually a good idea to have several intermediate checkpoints on notebook entries. Otherwise, the students procrastinate until the very end, defeating the purpose of the exercise.

2. Case studies or simulations: In case studies or simulations, students are asked to apply what they have learned to realistic problems or situations. Students could be asked to describe in writing how they would solve a particular problem or type of problem. Alternately, they could be asked to actually solve the problem and then to document and justify the solution in writing. Another activity which fits into this category is one in which students are given a computer program or a device (e.g., mechanical or electrical) without instructions and are asked to figure out how it works and to write about their findings.

Any type of writing assignment in which we provide instruction and/or a model of a written document and then require students to write a similar document fits nicely as a Quadrant 3 activity. We do this frequently when we teach students how to write a memo or a report and then require them to write a document on their own. Note that most homework assignments fall into this quadrant, although they would probably not be classified as writing assignments.

IV. Quadrant Four

Objectives

Quadrant 4 is the "student quadrant." The focus of this quadrant is on self discovery where students seek to apply the material and information which they have learned to their own lives or to simulated "real life" experiences. Individuals with this learning preference like to discover new ideas for themselves, and prefer learning by trial and error. Writing assignments in this quadrant should allow students to share their excitement for new things and to show how they can adapt a concept to new situations.

Writing Activities

1. Solution of the "What if?" formula: Solution of the "What if?" formula is a natural activity for this quadrant. In this activity, students are asked to create something new from the material which they have learned or to predict what will happen if the situation were changed. For example, students might be asked to write a response to questions like:

- What if the thermal conductivity were not constant, but increased significantly with temperature?
- How would this affect the design of the reactor?

Predictions such as those inherent in the "What if" activity represent a form of synthesis which is an important aspect of engineering design [20]. Expression of the response in writing further enhances student learning.

2. Freewriting: Another type of synthesis question which could be used as a freewriting exercise is a question which asks students to improve a particular product or device. For example,

- How can we improve the performance of this circuit?
- Can you think of a way to change the design of the reactor to reduce the variability of the product composition?

3. Problem preparation by students: Another writing activity appropriate for this quadrant is problem preparation by students. Note that the focus is again on the student rather than the professor. The formulation of problems allows the students to synthesize the knowledge from a course and often generates a much higher level of thinking than that usually associated with solving the normal set of application problems. This technique has been used on final exams where the students were asked to formulate a problem and solve it as part of the exam. Students have also been asked to make up questions prior to a mid-term exam as part of their homework. Students with the best questions have found themselves rewarded by the instructor using them on the exam!

IMPLEMENTATION

Although a writing activity may have been mentioned in a particular quadrant, it is not necessarily restricted to that quadrant. A writing activity may appeal to two or more learning styles for different reasons. For example, freewriting appeals to all four learning styles. It is useful for Type 1 learners because it is expressive of the self and one's feelings about a particular topic. It is useful for Type 2 learners because it offers time to think before responding vocally in class by writing a response on paper to a focus question. It is useful for Type 3 learners because it offers the opportunity to participate in an activity instead of listening to the instructor lecture. Freewriting is useful for Type 4's because it offers an open-ended activity with few restrictions, enabling Type 4's to explore and follow their creative impulses.

When considering the use of writing assignments, professors often worry about overloading themselves with paper grading. Another concern is not having sufficient time to cover all the necessary information; they think writing will take up too much class time. Writing-to-learn assignments however, do not have to be, and usually are not, graded [28]. Class time devoted to writing can be as little as five or ten minutes periodically and still be effective.

SUMMARY OF WRITING ACROSS THE CURRICULUM AND THE KOLB LEARNING CYCLE

This subsection has described connections between Writing Across the Curriculum and the Kolb Learning Cycle. Examples of writing assignments have been provided that relate to the various learning preferences defined by the Kolb learning model. The connection between writing and learning has been well established as discussed earlier. The learning cycle provides a way of relating writing assignments to particular educational objectives. It also provides a simple model which engineering faculty can use to plan and incorporate writing activities routinely into their teaching. It is hoped that the material in this sub-section will help educators to design writing assignments that will address the learning needs of all students in their classes and, perhaps most importantly, enhance the abilities of all students to learn.

4. IMPLEMENTATION AND SAMPLE LESSON PLANS

Previous sub-sections have provided examples of activities which can be used in each quadrant as we move through the Learning Cycle. The purpose of this sub-section is to address practical issues associated with the implementation of the Learning Cycle in our teaching and to provide sample lesson plans as illustrations of the method. As a reminder, the motivation behind the use of the Learning Cycle in the classroom is two-fold: 1) to reach all of our students by spending time teaching to each of the different learning styles, and 2) to teach our students how to traverse the full Learning Cycle for themselves (i.e., teach them how to become independent learners).

PLANNING

It is clear that we will not be able to successfully traverse the Learning Cycle in our teaching without planning ahead. Therefore, we need to plan the courses we teach around the Learning Cycle. As we prepare our courses for the next semester or term, we may want to consider the following steps:

1. Gather the Material. This step involves the choice of textbook and the accumulation of other resource material; this task, of course, is not unique to the use of the Learning Cycle. We usually expect to cover too much so we shouldn't get carried away at this point.

2. Define Concepts and Objectives. Again, this step is not unique to Learning Cycle teaching. However, a clear statement of concepts and objectives is essential to proper choice of classroom activities. As an anonymous writer put it "You have to know where you're going before you can figure out how to get there." A concept is a broad idea that helps to organize the material to be taught. In contrast, an objective is a specific task which the students are to accomplish. Objectives are associated with the skills which we want our students to develop and should answer the question "What do I expect the students to know when they leave?" For example, "Phase Equilibrium" is a concept. A corresponding objective might be the solution of an isothermal equilibrium flash. As we formulate our concepts and objectives we need to determine: 1) the personal value of the material for the students, and 2) the purpose in teaching the information.

3. Decide on timing. As we cover a particular topic, we should choose activities so that time is spent in each quadrant of the cycle. However, we do not need to spend time in each quadrant during every class period. It may take one, two, or more class periods to traverse the cycle for a given topic. For example, we may want to cover the first and second quadrants during a given class period and then assign a homework problem to the class as a third quadrant activity. The Type 4 activity may be completed the next class period or assigned as a self discovery activity to be performed outside of class.

Also, as we lecture on a subject (quadrant two), we may want to shift to quadrant three and have the students work a sample problem in class. Based on the feedback from the sample problem, we may need to return to quadrant two in order to supply additional information. Hence, the sequence in which the quadrants are covered is not nearly as important as the need to spend time in each quadrant. One exception to this is that it is often beneficial to open a class with some sort of Type 1 activity (which may be very short) in order to create the appropriate environment for learning.

SAMPLE LESSON PLANS

The next few pages contain sample lesson plans which span several different engineering topics. These examples demonstrate how one might develop a lesson plan which is designed to traverse the Learning Cycle. Sample Lessons One and Four each apply to a single 50-minute class period. Sample Lessons Two, Three, and Five cover multiple periods and involve out-of-class activities. Note that the activities in the lesson plans range from relatively simple to somewhat elaborate and complex. On a daily basis, straightforward techniques (e.g. questioning, didactics, etc.) can be used to routinely guide students through the Learning Cycle. A combination of these techniques with more elaborate activities will increase student interest, commitment, and learning. Careful planning and practical experience are both needed in order to optimize the choice of activities for a given topic. The important thing is to be creative and have fun!

Sample Lesson Plan 1

Civil Engineering 305 **Dr. S. Olani Durrant**
Properties of Materials **Brigham Young University**

Lecture 4--The Statistical Nature of Test Data

(Students have completed within the week uniaxial tests of steel, cast iron, and brass. They are seated in the classroom by lab group and have been asked to bring their test data and results.)

1. Pre-assessment (5 minutes)

- Inquire if there are any questions on past week's lab work.
- Have each lab group report their modulus of elasticity for steel. Record on board.

2. Motivation (Quadrant 1- WHY?) (5 minutes)

- Higher order questioning
  Why are there differences among the various laboratory results?
  Why didn't anyone have steel specimen with the "standard" modulus? etc.

3. Illustrated Lecture (Quadrant 2 - WHAT?) (15 minutes)

- Note sources of experimental error.
  (Page 50 of manual)
- Review statistical relationships.
  (Page 51 of manual)
- Introduce bell curve and the relationships of standard deviations.
  (Bell curve - see attached figure)
- Distribute reduced test data for 19 brass specimens.
  (Test data for 19 brass specimens - see Table A)
- Discuss mean and standard deviation for each property shown.
- Show histogram/bell curve plot for 19 values of ultimate strength.
  (Histogram/bell curve - see attached figure)
- Review and ask for questions.

4. Student Practice (Quadrant 3 - HOW?) (15 minutes)

- Distribute copies of bell curve/histogram.
- Ask each group to add their data for brass to the previous 19 and calculate new values for mean and standard deviation for each property.
- Have each group plot the values from their lab on the bell curve/histogram.

LEARNING ASSESSMENT

- Have a representative from each group come to overhead projector and add the value of ultimate strength for their lab specimen.
- Review concepts and correct any misunderstandings (shift back to Quadrant 2 as necessary to clarify concepts).

5. Applying (Quadrant 4 - WHAT IF?) (10 minutes)

- Point out that 98% of all values fall between plus or minus 2.33 standard deviations.

- "What if you were to use this brass for a tension member and you wanted to guarantee 99% success against fracture?"

  Think time and wait for responses

  "What would be your maximum stress?"
  "Translate that into a factor of safety on the mean value."
  "What are the problems with this design?
  "What factor of safety do you want?
  "Does that guarantee zero failures?
  "What is the probability?
- Continue as appropriate and as time allows.

6. Summary & Conclusions if time permits.

Table A
MECHANICAL PROPERTIES FROM UNIAXIAL TESTING
Brass Specimens

Specimen Number	Modulus of Elasticity (ksi)	.2% Offset Yield Stress (ksi)	Ultimate Strength (ksi)	Ductility (% Elongation in 2")
========	========	========	========	========
1	13900	43.6	56	20.5
2	14300	53.8	61.2	19
3	15300	45.7	59.3	22.5
4	14000	50	56.1	25
5	11600	43.5	54.9	36.5
6	13000	43.4	55	18.7
7	14400	44.3	56.8	19.8
8	13400	51.2	57.7	15.8
9	13900	47.1	55.7	16.3
10	14100	41.8	53.9	17.8
11	13200	42.2	54.6	23.6
12	10000	48	57.8	15.3
13	15700	46.7	60.4	29.7
14	15400	45.9	58.8	23.8
15	12700	51.4	58.8	15.8
16	13400	42.8	55	21.5
17	15500	53.1	63.2	20
18	13400	50.5	60.4	12.5
19	13300	42.2	55.5	22
20				
Mean	13711	46.7	57.4	20.8
Smpl.Std.Dev.	1377	3.9	2.6	5.5
Coeff. of Var.	10.0	8.4	4.5	26.6

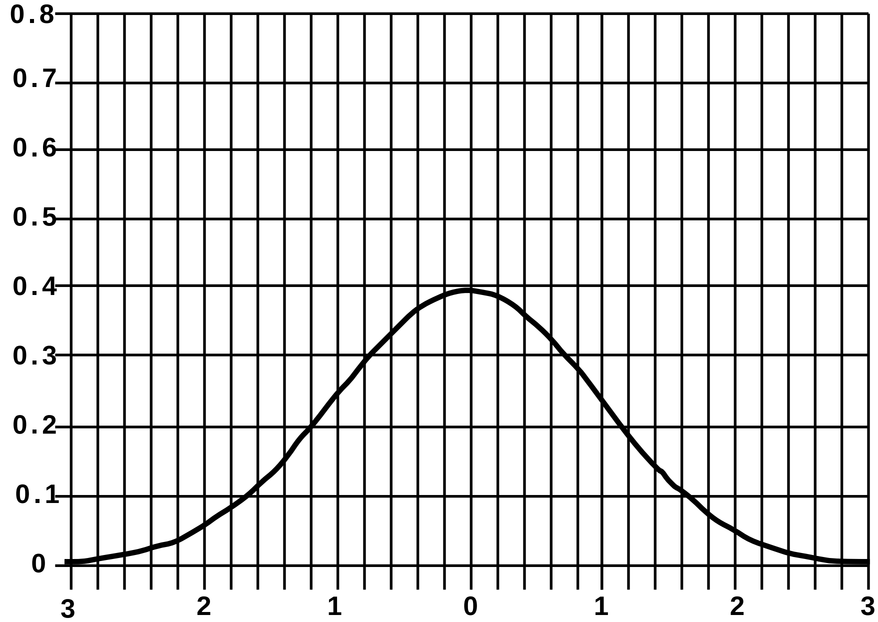


Figure 1. Normal Curve of Error

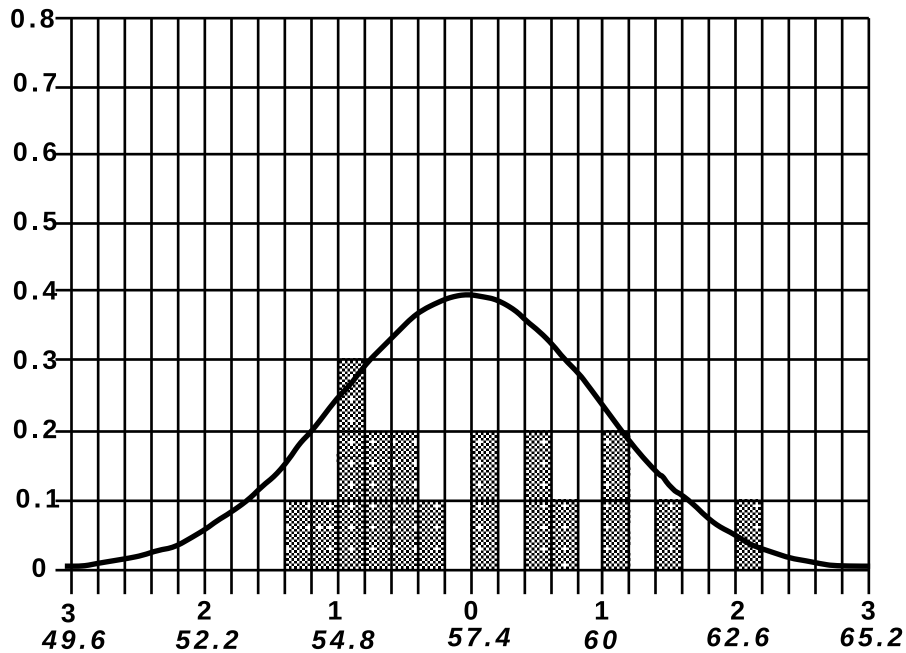


Figure 2. Histogram/bell curve plot for 19 values of ultimate s

Sample Lesson Plan 2

Chemical Engineering 436 **Dr. Ronald E. Terry**
Process Control and Dynamics **Brigham Young University**

The following lesson plan uses activities from each of the quadrants to teach the concept of tuning a feedback control loop. The figure at the end of the lesson outline shows the activities in the 4MAT system.

Concept to be taught: Tuning a feedback control loop.

1. Quadrant one activity

Higher order questioning.

Why is it important for a controller to be carefully tuned?
Based on previous discussion of feedback loops, etc., what information do you feel is necessary to tune a loop?

2. Quadrant two activity

Formal lecture coupled with instructor worked example problems.

Various tuning methods are presented and discussed.

3. Quadrant three activity

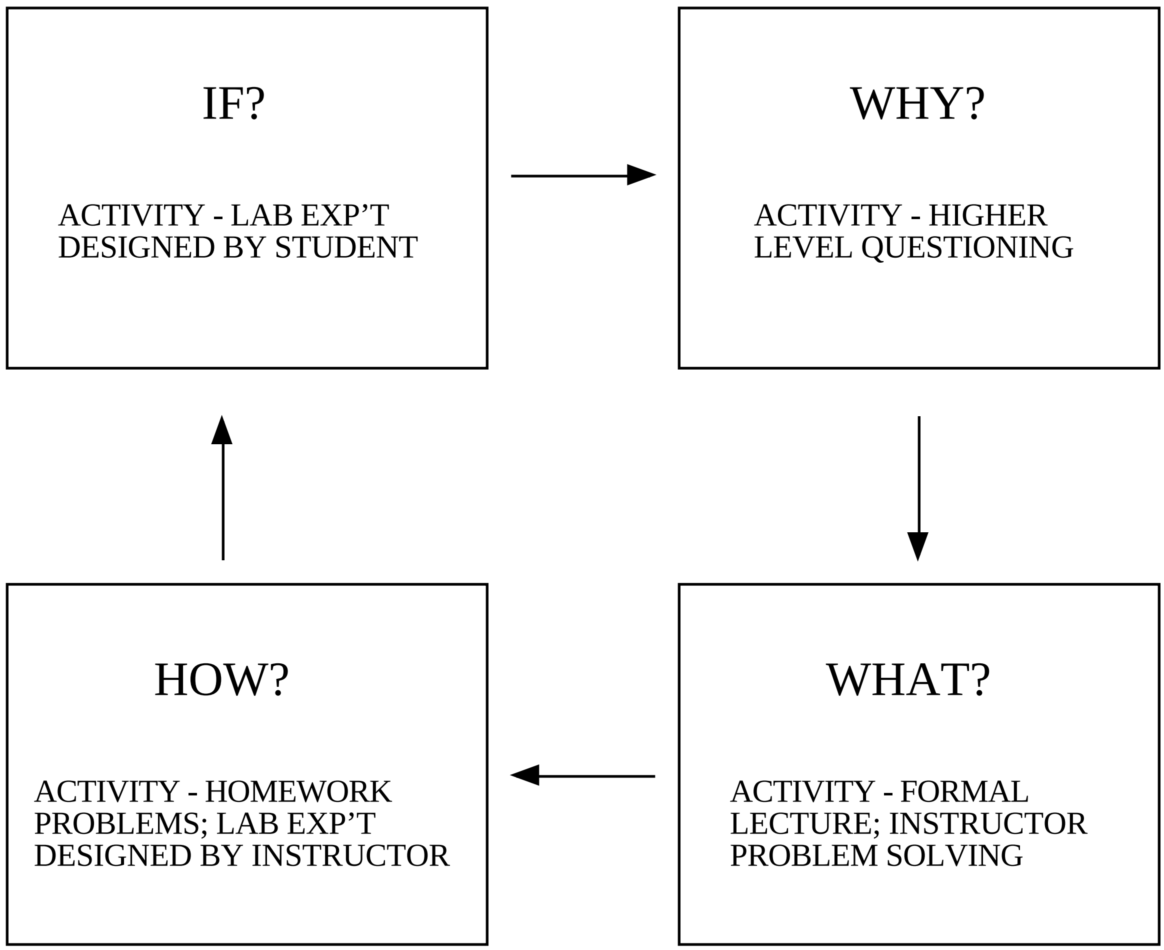
Homework problems and laboratory assignment of a carefully outlined and working experiment.

Application of tuning methods are presented in homework problems followed by an experiment in the Chemical Engineering unit operations laboratory. The experiment uses a carefully outlined procedure, which has been previously checked for errors, involving one of the methods discussed in the quadrant two activity. The procedure has been designed to give the students hands on experience with a control loop that is known to work and provide good control.

4. Quadrant four activity

Open-ended laboratory assignment.

In this lab assignment, the students are asked to use two or more of the tuning techniques discussed in the quadrant two activity to tune the loop. They are then asked to make a judgment of the quality of the control obtained with their techniques and discuss the results.



CONCEPT: TUNING A FEEDBACK CONTROL LOOP

Sample Lesson Plan 3

Construction Management 210 **Dr. Loren Martin**
Framing Methods **Brigham Young University**

Topic: Estimating Procedures for Framing Materials

Quadrant 1 Why? *Class Discussion*

Why is it important to develop accurate estimating procedures?

What potential problems may be associated with a poor estimation?

Personal Experience

Relate a personal experience which illustrates the importance of accurate bidding procedures.

Quadrant 2 (What?): *Lecture*

Provide formal instruction regarding estimating procedures for framing materials.

Quadrant 3 (How?): *Lab/Activity*

Students had previously worked together in groups of three as part of a lab section to construct a scale model of a house. Assign students to make estimates of materials and labor for floor framing, wall framing, and roof framing of the house. This assignment may be performed individually or as groups.

Quadrant 4 (What if?): *Simulation*

Students from the various work groups are re-assigned to a different work group of three students so that none of the previous partners are working together. They are to assume that they are a framing subcontracting company and are assigned to submit a bid for the framing of the house, including framing and sheathing materials, labor, and profit.

The reason that the groups are divided differently is so that each student is required to defend his/her original estimates. The group must then come to a consensus on the estimate and determine the bid price. All bids are called for at a predetermined time and are compared by writing them on the chalkboard. A discussion is held after this activity concerning actual bid-day practices and the necessity of being very accurate in estimating and bidding procedures so that you can develop as low a bid as possible and still be able to earn a profit if the contract is awarded to you.

This activity is usually performed during a two-hour lab section. It typically a very realistic experience with high student interest and interaction. The importance of teamwork and accuracy are emphasized.

Sample Lesson Plan 4

Electrical and Computer Engineering 220 — **Dr. Gene A. Ware**
Digital State Machines — **Brigham Young University**

Class 5 - Gates and Mixed Logic.

(The students have covered number systems and basic Boolean algebra.)

1. **Review** (5 minutes)

   a. Questions on assigned homework.
   b. Questions on Boolean algebra.

2. **Why?** (Quadrant 1) (5 minutes)

   a. Story of fatal F-16 flight when pilot attempted to "climb" over his target when in low level, inverted flight.

   b. You (the student) are asked to design a warning light which will light when the pilot is in inverted flight below a minimum altitude.

   c. The sensors and light control are TTL compatible. The inverted flight sensor and the low altitude sensor produce a low voltage when in inverted flight and at low altitude, respectively, and a high voltage otherwise. The warning light is lit when a low voltage is applied. Only an "OR" gate is available for the logic.

   d. Ask the students how to design this simple problem using the given device. Some will see the negative logic solution. Initiate a discussion on designing with both positive and negative logic called mixed logic design.

3. **What?** (Quadrant 2) (20 minutes)

   a. Using an interactive, question based lecture, develop the following diagram on the board.

Boolean World	Hardware World
1. Boolean Values 0,1 2. Boolean Variables 3. Boolean Equations 4. Truth Tables 5. K-Maps Define: Asserted = 1 Not Asserted = 0	1. Voltages - high, low 2. Hardware signals 3. Logic is performed by hardware 4. Function Tables

b. Questions which could be asked include:

- What is in the Boolean world? (Boolean zeros, Boolean ones, Boolean variables, Boolean equations, truth tables, K-maps, etc.)
- What is in the hardware world? (Hardware devices, integrated circuits, gates, voltage measurements, device function tables, etc.)
- Boolean world: Can you hold a Boolean one? Can you measure a Boolean one with a meter? Can you measure a voltage in the Boolean world?
- Hardware world: Can you hold a piece of hardware (a gate chip, for example)? Can you measure a Boolean one with a meter? Can you measure a voltage in the hardware world?

c. Include the idea that Boolean algebra is conceptual and is used as a theoretical tool in the design and modeling of digital circuits just as the calculus is used as a theoretical tool for modeling the physical world around us.

d. The Boolean world speaks a language of zeros and ones. The hardware world (TTL, at least) speaks a language of high and low voltages. A translation rule is needed to relate the two worlds.

e. Defining the word "asserted" to mean one in the Boolean world, define the asserted-low (1-low) and asserted-high (1-high) translation rules.

f. Show how this translation works with the so-called "OR"gate.

TRUTH TABLES
(Boolean)

Boolean "OR"

A	B	F
0	0	0
0	1	1
1	0	1
1	1	1

Boolean "AND"

A	B	F
0	0	0
0	1	1
1	0	1
1	1	1

Asserted-High (High Voltage = 1)

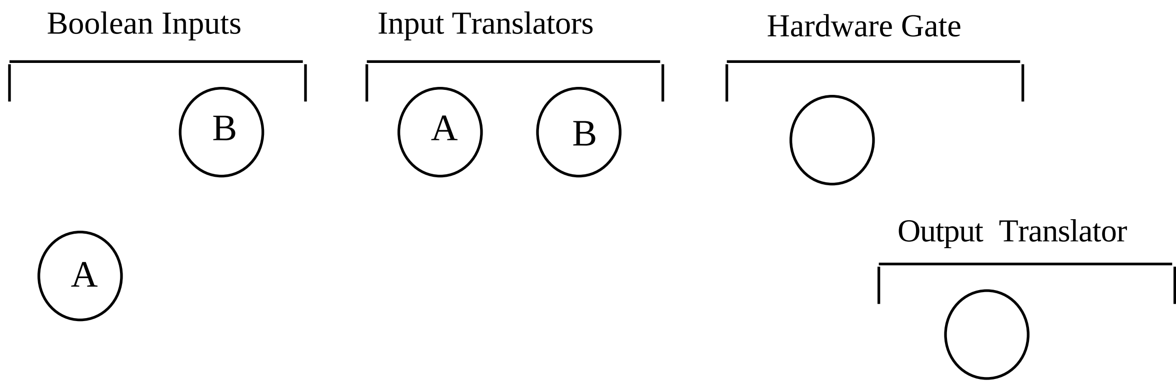
Asserted-Low (Low Voltage = 1)

FUNCTION TABLE
(Hardware)

A	B	F
0	0	L
0	1	H
1	0	H
1	1	H

4. How (Quadrant 3) (10 minutes)

a. Ask for seven student volunteers. Arrange them as follows:



b. The A and B Boolean input students are given large cards with a "0" on one side and a "1" on the other side. The A and B input translators are given large cards with a "L" on one side and a "H" on the other side. The hardware gate student (the only one with any logic) is given a large "L" and "H" card. The output translator is given a large "0" and "1" card. The seventh student serves as a scribe to record the results.

c. The input translators translate the input Boolean values into voltages. The output translator translates the gate output voltage into a Boolean value. Instruct the hardware gate to perform the hardware operation defined by the function table for the "OR" gate (which is listed on the board for reference) based on the voltages displayed by the input translators.

d. Instruct all translators to use the asserted-high (1-high) translation rule. Walk the Boolean inputs through the four possible input combinations and record the results in a truth table on the board.

e. Instruct all translators touse the asserted-low (1-low) translation rule. Instruct the gate to perform according to the same function table. Walk the BOolean inputs through the four possible input combinations and record the results on the board.

f. Compare the two truth tables (Boolean world) obtained from the function table (hardware world) by using the two translation rules. The aserted-high rule causes the "OR" gate to perform the Boolean "OR" operation. The asserted-low rule causes the same "OR" gate to perform the Boolean "AND" operation. Note that a similar condition holds for the "AND", "NAND" and "NOR" gates.

g. Observe that the F-16 design problem can be solved by using the "OR" gate with the asserted-low translation rule which matches the voltage specification of the sensors and the warning light.

5. **What If?** (Quadrant 4) (10 minutes)

a. Give the students a handout containing the function tables for two input "AND", "OR", "NAND" and "NOR" gates. Stress that these names do not define the Boolean operation performed by the gate. This will be determined by the translation rule to be used.

b. As a homework assignment, have the students ask **What If** the following assignments were made (i.e., what Boolean functions are performed):

- The inputs to each gate were asserted-high and the output was asserted-high.
- The inputs to each gate were asserted-high and output was asserted low.
- The inputs to each gate were asserted-low and the output was asserted high.
- The inputs to each gate were asserted-low and the output was asserted low.
- What changes if one input is asserted-high and the other input is asserted-low?

6. **Summary and Conclusions**

Sample Lesson Plan 5

Manufacturing Engineering 232 **Dr. Robert H. Todd**
Manufacturing Processes **Brigham Young University**

The following brief lesson plan outlines activities from each of the four learning quadrants intended to help students learn the importance of considering *design for manufacturability* of a device in the *early* stages of design.

1. Quadrant one activity: (Why?)

Socratic or higher order questioning

- *Why* is it important to consider manufacturability as well as functionality in the early stages of the design process of a device or product?
- *Why* is the designer responsible for these considerations?
- *Who* else is responsible and *why*?

2. Quadrant two activity: (What?)

Formal lecture including review of cost sources in manufacturing

- How the total cost of manufacturing is divided up, design, materials, labor, burden, etc.
- The cost of engineering changes from concept selection to final production. The rule of 10's.
- *Review* check lists of features that can be *designed into* a product to improve manufacturability.

3. Quadrant three activity: (How?)

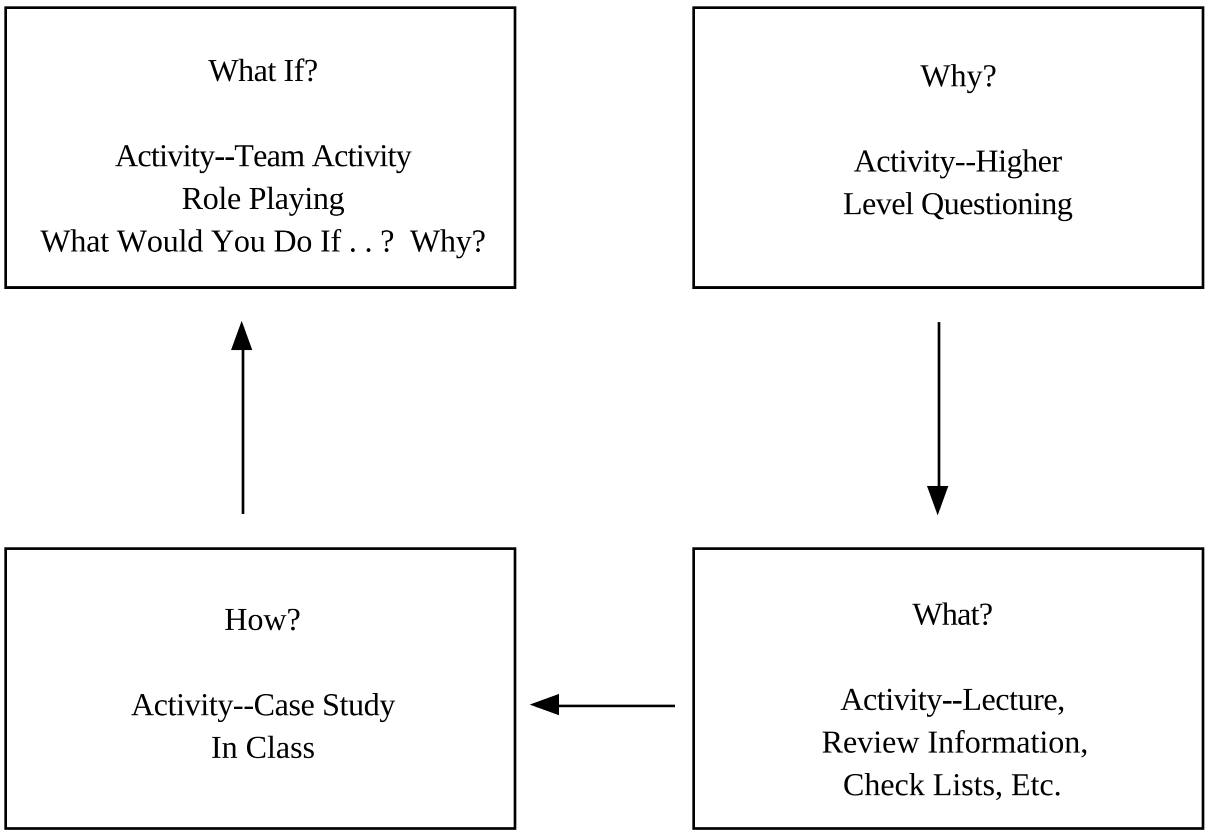
Reverse engineering case study

- Review design features of an inexpensive simple consumer device that make manufacturability easy or difficult.
- How could the existing design be changed to improve its manufacturability, cost, quickness to market, quality, etc?

4. Quadrant four activity: (What if?)

Reverse engineering team assignment

- Suppose you are assigned to work with a team of employees to reverse engineer a competitor's product and improve the manufacturability of the product by altering the products design. What would you do and why, using information you have learned? Student team picks product and does redesign.



SUMMARY OF QUADRANT ACTIVITIES
FOR SAMPLE LESSON PLAN 5

SECTION III

TEACHER DEVELOPMENT PROGRAM AT BRIGHAM YOUNG UNIVERSITY

The purpose of this section is to describe a teacher development program that was implemented within the Engineering and Technology College at Brigham Young University.

INTRODUCTION

Most beginning faculty have been associated with research programs in their careers, either while obtaining doctorate degrees and/or in industry. This association provides experience in writing proposals, obtaining funding, conducting experimental and/or modeling programs, writing final reports, and preparing papers for presentation. However, formal Ph. D. programs generally do not provide faculty with training in teaching methodology. As a consequence, new faculty often struggle with the basic elements of teaching, i.e., how to organize a class and write a class syllabus; how to conduct the day-to-day educating with lectures; etc; and how to formulate examinations to determine the extent of learning. These are not trivial tasks. They require long hours of thought and care before they are performed well. Often a faculty member's training becomes what he/she has observed others do. Therefore, good or bad, the system tends to perpetuate itself.

In addition, the reward system is not always conducive to allow faculty to spend the time necessary to develop their skills in teaching. Many institutions place more emphasis on developing a productive research program than on developing teaching skills. Improvement in teaching requires time, resources, and effort. If faculty feel that their attempts to improve their teaching are detracting from their research efforts, they often do not feel motivated to work on improving their teaching. Another aspect of the reward system is that good teaching is difficult to measure. If student evaluations are reasonable and not negative, then many faculty feel they are doing "fine" and they do not see the need to improve.

Improvement in teaching often requires an element of change. Change can be frightening and risky, taking individuals out of a comfort zone and into an area of unknown. Rather than risk the unknown, many faculty will fall back to their previously developed styles, particularly if their teaching has been "adequate".

The Engineering and Technology College at Brigham Young University has had a Teacher Development Committee for several years. This committee was given the charge to address some of the concerns mentioned above. In particular, the committee is responsible to conduct a training seminar for new faculty at the beginning of each fall semester and also to conduct an annual college teaching conclave. The conclave has usually involved a presentation by a member of the BYU Education or Educational Psychology faculty. These presentations have always been good and have stimulated discussion of teaching within the engineering and technology faculty. But often the discussions only last a few hours to a few days, and then people return to the status quo. It appeared to members of the Teacher Development Committee that a long term program was needed in order to make an impact on college teaching performance. As the committee members sought such a program, they learned of a workshop presented to civil engineering department chairs at regional meetings across the country sponsored by the American Society of Civil Engineers. The workshop focused on learning-style theory and improving teacher effectiveness. The material presented in the seminar was referred to as the Integrated Learning System (ILS). Arrangements were made for the dean's office to fund a member of the committee to attend an ILS workshop. More will be said later about the support of the dean's office which has been vital to the implementation of the teacher development program at BYU. After attending the seminar, a recommendation was made to the Dean's office that a proposal be requested from the presenters of the seminar which would allow ILS to be taught to the entire BYU Engineering and Technology faculty.

The purpose of this section of the monograph is to describe how the ILS program was implemented and to provide observations and experiences on its efficacy at BYU [32,33].

BYU PROGRAM

In December of 1988, a member of the Engineering and Technology College Teacher Development Committee attended a seminar on the Integrated Learning System (ILS). This seminar was organized by Dr. Kenneth J. Williamson, Professor of Civil Engineering at Oregon State University, and Dr. Pamela K. Hurt, consultant, and was presented by Dr. Williamson. Subsequently, the organizers were asked to submit a proposal to the BYU College of Engineering and Technology to present the concepts of ILS to the college faculty.

In February of 1989, at the annual college conclave on teaching, Drs. Hurt and Williamson presented a two-hour seminar to the faculty. During the seminar, faculty were asked if they were interested in participating in a rigorous training program involving ILS. About 1/3 (35 out of 100) of the college faculty volunteered to participate. A date of August 1989, one week before the start of Fall Semester 1989, was agreed upon to begin the training. Materials were sent in advance for the faculty to begin assimilating the concepts of ILS. In August 1989, consultants Hurt and Williamson conducted two days of training. The first day of training consisted of the material that was presented at the seminar in December of 1988. The entire college faculty were invited to attend the first day's presentation. Nearly 80% of the faculty were in attendance. The 35 volunteers participated in the second day of training. The volunteers were instructed on how to prepare a course syllabus containing activities which would incorporate the ILS concepts. Specific examples of both in-class and out-of-class activities in each of the quadrants were presented. Higher level questioning techniques following Bloom's taxonomy were also discussed [13, 14].

The volunteers proceeded to implement the concepts during the fall semester. Volunteers were encouraged to visit each others classes, to evaluate, and to provide feedback for their colleagues. Both audio and video taping were done to help with the evaluation process. Many faculty were apprehensive of these taping sessions, particularly the video taping. However, those who used the taping techniques found them instructional and helpful. The volunteers were divided into support groups and were asked to meet on a regular basis to share successes and failures that they had experienced during the semester. These support groups became one of the most significant benefits of the training program. Many faculty were having regular discussions about teaching for the first time.

. . . Many faculty were having regular discussions about teaching for the first time. . .

A follow-up training session with the consultants took place at the end of fall semester in December 1989. The volunteers were asked to prepare a poster for a poster session. This poster session was opened to the entire college faculty. Many successful activities were reported by the volunteers. New ILS concepts were introduced by the consultants as well as the change model discussed below. At the 1989-90 annual college conclave on teaching, the posters were again displayed and several volunteers reported on their experiences in the class room with the new ILS concepts.

The final training session with the consultants took place in December 1990. A few of the volunteers were asked to present a short presentation simulating a classroom experience. The volunteers were asked to demonstrate how they traversed the four quadrants in order to provide a positive teaching experience for all learning types. The presentations were very well done indicating that many of the volunteers had been successful in learning the ILS concepts and incorporating them in class room instruction. Additional material on the change model and the flow of knowledge within the brain was presented by the consultants.

CHANGE MODEL

The challenge which the Teacher Development Committee faced was to stimulate the college faculty to willingly change their instruction methods, i.e., to abandon their comfort zone and try something new. The change process observed at BYU can be modeled by the Concerns-Based Adoption Model (CBAM) developed at the Research and Business

Development Center at the University of Texas [34,35]. CBAM is highly respected in industry and is designed to orchestrate organizational change. This seven-step conceptually-based model helps organizations change progressively to meet the desired objectives. The seven steps are shown in Figure 11. There are three assumptions used as a premise for this model: 1) change is made by individuals first and then by organizations; 2) change is a highly personal experience and involves the personal growth of all involved; 3) change must be managed by relating to people first and the change second.

PROCESS OF CHANGE

(CONCERNS-BASED ADOPTION MODEL:CBAM)

STAGE 6: REFOCUSING

STAGE 5: COLLABORATION

STAGE 4: CONSEQUENCE

STAGE 3: MANAGEMENT

STAGE 2: PERSONAL

STAGE 1: INFORMATIONAL

STAGE 0: AWARENESS

Figure 11. Seven Steps in the Process of Change.

In August of 1989, the consultants began with the BYU engineering faculty at steps 0 and 1 by building an awareness of the need for change in the area of college teaching methodologies and giving necessary information concerning the status of engineering education. Approximately 80 members of the College of Engineering and Technology faculty participated in this phase of the program.

In the December 1989 training session, the consultants had a goal of moving a core cadre of faculty to steps 2 and 3 of the change model. Volunteers were requested at this point in the program to commit time and resources; thirty-five members of the faculty volunteered. Support by the dean and department heads was imperative in moving individuals through the change cycle successfully. Higher-level questioning techniques were taught with both video- and audio-taping of volunteers' instructional deliveries. The volunteers left with a commitment to incorporate new teaching techniques into their existing curricula.

The implementation stage of change (steps 3 and 4) was achieved by the formation of support groups, by discussion of innovative teaching ideas at faculty meetings, and by modeling class presentations for one another. In the December 1990 training session, a trainer of trainers program was presented to the remaining volunteers which numbered 20. It was felt that these remaining volunteers were somewhere near stages 5 and 6 on the change process after the 1990 December training session. New research on the way information is perceived and processed in the brain was presented during the 1990 December session.

As the engineering and technology faculty participated in the program, several barriers to change were identified. These included: skepticism, lack of motivation, vulnerability, inadequate resources, lack of clarity about the change, and the need to take time from other activities deemed more important to promotion and tenure.

OBSERVATIONS AND TESTIMONIALS

During the training session in December of 1989, these observations were made: 1) many courses were entirely redesigned based on the ILS training; 2) new instructional activities were tried and in many cases implemented by faculty who had previously relied on a traditional lecture based format; 3) the majority of participating faculty taped their instruction to determine the use of higher-level questions; 4) many examples were provided of how a 50 minute lecture was broken down into two or three time periods with a different type of instructional activity being used in each period; 5) unique examples were presented on how faculty engaged the students in class with group activities coupled with faculty coaching; 6) all of the volunteers expressed increased personal satisfaction with their teaching; and 7) enthusiasm for the program led to increased faculty discussions about teaching and learning.

Comments were solicited from several volunteers at the end of the December 1990 training session. A few of these comments are presented here.

I participated in the ILS program because I wanted to improve my teaching in an organized fashion with a global view rather than in an *ad hoc* fashion based on isolated ideas that seem good at the time. The 4Mat teaching system provides the global view. I have implemented it in my classes, and it has been very rewarding. It gives me a model that I can proactively work with to improve my teaching performance rather than simply relying on my "natural ability (or inability)".

I was amazed at how blind I had been to assume that my students were right with me during my lectures. The 4Mat system helped me to realize that in addition to conveying concepts, I must first grab the students' interest, provide hands-on, engaging activities to let concepts sink in, and give the students opportunity to take these concepts and run with them by integrating them into real-world projects.

I have used this model in my undergraduate structural analysis course. I have had many positive comments from students -- particularly about the design projects that I assign. Some students have said that this is the first course in which they have felt like they were doing real engineering work. - *Rick Balling of the Civil Engineering Department.*

Looking back on my participation and the effect that it has had on my teaching I feel strongly that it has had a positive influence in two principal ways:

1) My effort as a faculty member to pass through the four types of learning activities has definitely increased. I suppose for some time I used this type of approach in my teaching both in industry and before that in academia but now I have some theory and explanation as to why it is important and why it ought to be done.
2) The four step process is definitely a

practical and simple reference frame to use as a skeleton for any concept, technique or principle that needs to be taught. I believe that even though all of us as faculty and students may tend to have a dominant learning style, my experience has shown me that providing learning experiences in all four of the quadrants enhances learning for just about every person no matter what his predominant or preferred learning style quadrant might be. As a result, my effort in designing learning activities is much more diverse than what it was previously.

As a result of my participation in the ILS Program I have definitely become even more sensitized to the importance of having students be involved in the learning process through the use of higher levels of thinking. It's not enough for most students to just be exposed to information; they have to think about questions like "why", "what if" and "how". They also need to "do" some things. I have seen many instances where students retain and understand much better when these higher levels of thinking have taken place with the subject at hand. I find myself spending time developing these types of questions and activities in my lesson planning more so than in the past. - *Robert Todd of the Technology Department.*

The Kolb learning cycle provides what a well founded model on which my teaching and teaching effectiveness assessment can be based. This fundamental learning cycle model has had a far greater impact on my teaching effectiveness than has any specific teaching style change. Prior to working with the ILS program, my teaching style was based on inputs from several sources including:

1. The College of Education. This source was not very effective.
2. Suggestions from and observation of colleagues. Effective techniques used by others did not always work well for me.
3. Student comments and evaluations. This input tends to be short term and somewhat of a popularity contest.

The Kolb learning model provides the basis for effective course planning and for dynamic interaction with the students in the classroom. This is especially important in large classes where individual attention to each student is not possible. The key elements, at least to me, are:

1. Didactic loading, no matter how well it is dressed up, is only part of the story. If retention is desired, the teaching must include the other teaching (learning) styles. This may require changes in the "course content."
2. The 18 minute law. Change the teaching style several times in a class period.
3. ALL students will learn and retain more if the course material is presented using all four teaching (learning) styles.

Application of the Kolb learning cycle to teaching takes effort. It is probably the most effective model for what teaching is all about that I have encountered in the last fifteen years. - *Gene Ware of the Electrical and Computer Engineering Department.*

SUMMARY

In summary, a unique faculty instructional development program has been implemented within the College of Engineering and Technology at Brigham Young University. Three key elements were essential to the successful implementation of the program. These were: 1) dedicated faculty volunteers who were (and remain) sincerely interested in teaching; 2) strong support from the college Dean's office; and 3) a Teacher Development Committee that served as a catalyst for the effort.

The program was funded entirely by the Dean's office and cost $11,500 in actual expenses. These dollars were spent on 175 man-days of instruction and training of faculty, a cost of less than $66/man-day.

Renewed interest and enthusiasm towards teaching has developed with the participating BYU faculty. Faculty who are creative, but who have hesitated to bring that creativity into the classroom, now perceive a rational basis for expanding learning activities beyond the lecture, and are encouraged by the systematic nature of the Kolb Learning Cycle to do so. This has renewed their enthusiasm for the educational process and has eliminated much of the formal stiffness in the classroom. Student comments have been positive about the change in teaching strategies being used.

CONCLUDING REMARKS

This monograph is intended as a resource for the enhancement and improvement of engineering education. The Kolb Learning Cycle model, has been used as a basis for improved instruction. This model was patterned after McCarthy's 4MAT system [2] and was based on elements of learning style theory from the work of Kolb [1]. The Kolb model is not the only effective learning model available and is not without limitations. However, the Kolb model does provide a logical and useful foundation on which to build. In addition, the Learning Cycle model may be applied by all faculty, independent of their own teaching styles.

We believe that engineering education can be significantly improved through the use of more effective teaching methodologies such as the Learning Cycle discussed in this monograph. The motivation behind the Learning Cycle (Why?), learning style theory (What?) and implementation of the cycle (How?) have all been discussed in the preceeding pages. It remains for each faculty member to weigh the benefits/risks of applying the learning cycle theory to his/her own classroom instruction. In other words, the relevant questions for each of us, as engineering educators, become (What if?):

> How can I apply the Kolb Learning Cycle in my own teaching?
>
> How can I make use of the Kolb Learning Cycle to help my students become more independent thinkers and learners?

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