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: 1) 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: 1) 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 1) 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.).

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.

### 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
4. **Group Discussion:** Introduce the topic of discussion and then divide the class into groups with the assignment to determine, for example: 1) 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.](image)

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.

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 into 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/REMEEDIATOR.**

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:

- 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. 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, defeated 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!