WHAT WORKS
A Quick Guide to Learning Principles

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Great teachers may be born that way, but the vast majority of professors have to *work* to improve their teaching. Fortunately, a research base now exists that shows which teaching methods work in a variety of situations. In this paper, ten of the procedures which are known to work will be briefly presented and applied to chemical engineering education. More details and a variety of earlier references are given by Wankat and Oreovicz.[1]

TEN LEARNING PRINCIPLES

1. Develop a structured hierarchy of content and guide the learner.

Content is king (or queen). The professor should be sure that the content of his subject is both important and up-to-date. Some structure should be evident to the students, and they should be guided in their learning. Tell the students where they are going and why it is worth their effort to get there. For example. thermodynamics is both beautiful and extremely useful, but many professors act as if the beauty of thermodynamics alone should be sufficient to hold their students' attention, and they neglect to tell the students what they will be able to do once they have mastered the subject. Be sure that the students know what the objectives of the course are. Actually developing some of the structure of knowledge themselves helps students learn the material; thus, an overly rigid structure should be avoided. A good homework assignment is requiring the students to prepare a "key relations chart" which lists everything the student wants to know to solve problems or for a test. Obviously, first-year students need considerably more structure than graduate students, and courses should be designed accordingly. Since problem solving is a major part of chemical engineering, both the structure and the method of problem solving should be part of the course.[1,2] Much of the structuring of content and guiding the student can be done in lectures, although other teaching methods work just as well if not better.

2. Develop images and use visual modes of learning.

Most people prefer visual learning and remember visual images much longer than words, but most college instruction is auditory (*e.g.,* see Felder and Silverman[3]). The McCabe-Thiele diagram has been a successful teaching method for decades simply because it provides the student with a visual image. Modern computer graphics and plotting calculators can also be used to provide visual images—they are particularly useful for three-dimensional plots and for showing motion. Most students better understand equations when they are plotted for a variety of circumstances rather than simply looking at the symbolic form. The professor should require that the students develop their own visual images.

3. Make the students actively learn.

People learn best by actively grappling with information; thus, some sort of classroom activity is required.[4] This activity can be external (such as discussing a question, solving a problem, developing a structured flowsheet of knowledge, brainstorming, or working in a group) or internal (such as reading, questioning by oneself, pondering, etc.). Lecturing without student interaction is active only for the

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professor—which is one reason why professors often feel they have learned more than anyone else in the class. Most students will initially resist active involvement in the classroom since it is not safe and they have been trained to passively take notes. But once the students become familiar with classroom activity, they usually grow to like it—and most students certainly benefit from it.

4. Practice and feedback.

The professor should provide the students with an opportunity to practice what they learn while they are still in a supportive environment. A variety of different problems and questions should be tackled, and it is important to have some (but not excessive) repetition to increase both speed and accuracy. A series of regular assignments with frequent feedback will elicit more work and higher levels of commitment to the class than will one long assignment.[5] Following this principle, a long design project can be broken into several smaller parts with various assigned due dates. Students should have feedback during, or shortly after, their first practice so that they do not keep practicing incorrect methods.[2] Feedback a month later is not useful. The students should have the opportunity to practice again—after they have received the feedback. For instance, after a laboratory or design report has been returned to the student with the usual excessive amount of red ink, it is most effective to require the student to produce a final, corrected, clean copy. With the aid of word processors, preparing a clean copy is much less work than it used to be. Computer-aided instruction can provide very useful practice, particularly if it is interactive.

5. Positive expectations and student success.

Studies have shown that when a teacher *expects* students to do well, they usually respond by doing well.[4] When someone important believes in the student, his or her expectations can be a major influence in the student's success. A very interesting and accessible report on this topic, pertaining to families, is given by Caplan, *et al.*[6] Success is a strong motivation in itself, and it leads to additional success. When a student does not have the proper educational background, he or she will be probably be unsuccessful; so one useful activity is to provide background material for those students, and then to make sure that they use it. For instance, a lack of skill in algebraic manipulation will certainly sink a student in a mass and energy balance course—extra help in algebra can be much more effective in advancing that student than tutoring in mass and energy balances. Many capable students

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leave engineering due to a lack of encouragement or a lack of success.[7]

6. Develop a cooperative class with students teaching each other.

Most students learn better in a cooperative environment where a significant amount of the work is done in groups.[4] Since modern engineering practice usually involves groups of engineers, group classwork can be good training for the students' professional careers. Many students who leave engineering cite the overly competitive atmosphere as a major reason for leaving.[7] A number of successful programs involving group work with engineering students have been reported.[1,2] A recent study at Harvard University found that the students who grow most academically and who are happiest structure their time to include intense interpersonal interactions with faculty or other students.[5] In large classes the professor may not have time to meet individually with every student, but he or she can and should encourage group work both in and out of class. Study groups should be set up with the understanding that each group member must do the reading or problem assignments before coming to the study group. Optimum group size appears to be from four to six students. Competitive grading procedures using "the curve" do not encourage cooperation; other procedures, such as grading against an absolute standard or mastery testing, will encourage more cooperation with the professor and between the students themselves.[1] One advantage of working in groups is that students have an opportunity to informally teach other students (which helps both of the students learn better). Formal approaches to encouraging students to teach other students (such as tutoring or serving as the expert on a laboratory experiment) also increase student learning. It is important to note that teaching others should *not* be reserved for only the best students.

7. Be enthusiastic—care about teaching.

Students respond to enthusiasm. It is important that the professor *cares* about what he or she is teaching. Those professors who put teaching on "automatic" cannot possibly do a good job. There is no excuse for reading a book to the students in lec-

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ture—it is boring and shows a tremendous lack of respect for both the students and the material. Enthusiasm and caring (both for the students and for the material) are so important that they are sufficient to help cover a variety of other teaching sins. One advantage of professors teaching courses in their research areas is that most of them are naturally enthusiastic and caring about their subject. Of course, someone still has to teach the beginning courses, and it is vitally important to also show a love of learning in them. Small classes can be a big advantage since it is easier for professors to show enthusiasm and caring when there are fewer students. Small classes almost force personal interaction between students and faculty. It has been shown that students who took small classes early in their careers were much more likely to become engaged in academics.[5]

8. Challenge the students— ask thought-provoking questions.

Many students leave engineering because they see it as boring![7] To offset this, the professor should find ways to provide some measure of challenge to each of the students. One method is to ask questions which "stretch" the students, requiring that they use their fundamental knowledge in new ways to answer questions about real phenomena. For example, ask what the temperature will be in a car sitting on the street if the wind chill is -10°C but the ambient temperature is 20°C—then ask the student to explain what "wind chill" is. It is often a good idea to leave a question unanswered during class and to challenge the students to obtain an answer within their study groups. The challenges should be arranged so that each student can shine once in a while.

9. Individualize the learning environment.

Since students have very different learning styles,[1,3] it is useful to employ a variety of teaching styles throughout the course. In that way each student will be able to use his or her favorite style at some time during the course. The professor should use both inductive and deductive approaches to teach the material, although an inductive approach is usually more effective the first time through the material. Use a variety of different exercises—when brainstorming is one exercise and analysis is a second exercise, you will often be able to observe that different students shine in the different exercises. Rich Felder's column, "Random Thoughts" in *CEE,* has contained many examples of individual learning styles and methods to individualize instruction in chemical engineering.

10. If possible, separate teaching and evaluation.

Evaluation gets in the way of teaching since the evaluator tends to be seen as the "enemy," particularly if grading is done on the curve. The professor who separates teaching and evaluation can then become a coach who is there with the sole purpose of helping the students learn. Someone else should do the evaluation, or a mastery style course where every student can succeed should be used. For example, in a large multisection course with several professors, one of the professors could write and be in charge of scoring all tests and quizzes while the other professors do the teaching. In a design course, an industrial evaluation of the designs may well be appropriate—it is certainly realistic.

CONCLUDING REMARKS

These learning principles are certainly not inclusive, but they do present a good start for improving teaching and avoiding disastrous classes. Note that most of the focus of these principles is on the students. It is the students, not the professor, who have to learn in order for the course to be a success.

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