

A SELF-PACING, AUTO-GRADED COURSE*

G. DAVID SHILLING
University of Rhode Island
Kingston, R. I. 02881

INTRODUCTION

A two-credit course in reactor engineering, required for senior students in Chemical Engineering at the University of Rhode Island, has for the past three years been operated in an auto-graded mode (so called because the student supposedly decides what grade he will get.) Because the senior classes are not large, only one section of the course was scheduled each year, and all the students participated in this experimental program. Except for three graduate students, the students have all been seniors. A wide range of scholastic achievement levels has been represented — from students headed for graduate school, down to some on the verge of being dismissed.

The goal of the experimentation was to find a way out of a situation where the instructor met two hours a week with a well-knit little group of tired students willing to let him do all the talking and most of the work. It was hoped that by using the auto-graded mode, which was described in ASEE Publications, first by Norman Balabanian¹ and then by Roland Mischke², the more ambitious students could be released from the lock-step pace and the dependence on the instructor; and by requiring each student to take the initiative for his progress toward a passing grade, the less ambitious students would be confronted with some facts of life.

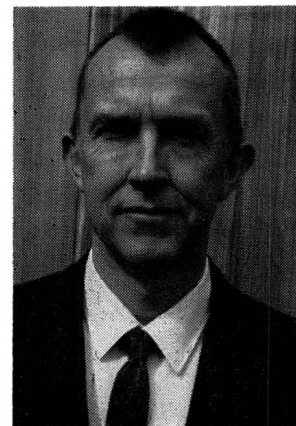
DESCRIPTION OF COURSE

The rules governing the operation of the course are shown in Table I, the "Course Plan" which was distributed to the students at the beginning of the course. A student's progress through the course is marked by his passing a series of tests, and his course grade is determined by the number of tests he passes (eight for an A, seven for a B, etc.). Each test "covers" one chapter in the textbook by treating in detail a set of problems illustrating the principles set

¹N. Balabanian, "Removing Emphasis on Grades," *J. of Eng. Ed.*, 54, No. 7 (March 1964).

²R. A. Mischke, "A Semitutorial Approach to Teaching," *J. of Eng. Ed.*, 56, No. 3 (November 1965).

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G. David Shilling is a graduate of the University of Delaware and the University of Wisconsin (PhD '50). He taught at Kansas State and is now completing his seventeenth year on the URI faculty. He developed an interest in process control at summer institutes at Case Institute and the University of Colorado and published *Process Dynamics and Control* in 1963. Since his participation in the ASEE's Programmed Learning Project (1965-66), he has experimented with programmed instruction and self-paced and auto-graded courses.

TABLE I — COURSE PLAN
Chemical Engineering 64 — Fall 1967

The text book will be *Chemical Reaction Engineering* by Octave Levenspiel.

The instructor will select and announce a set of problems for each chapter as follows: Chapters 2, 3, 5, 6, 7, 8, 14, 13.

A student will obtain credit for a chapter by scoring 90% or better on a written examination on the chapter. Only then will he be eligible to take the examination on the next chapter, in the order shown above.

Examinations will be limited to 55 minutes. They will be given at 1 P.M. on Monday, Wednesday, and Friday, between September 21 and January 13, school holidays excepted.

The instructor will retain all copies of the examination papers and questions. A student may see and discuss his examination paper when convenient.

A student's course grade will depend on the number of chapters he passes as follows: eight, A; seven, B; six, C; five, D.

forth there. These problems are much more involved than a student could be expected to work "from scratch" in an hour examination. But the students are given the problems in advance and have worked them and perhaps discussed the solutions with the instructor and other students.

It is assumed that each student will choose what course grade he will get and decide when he will pass the required tests for that grade. To help the student pace himself through the semester, he is given a copy of the "Experience Table" for last year's class. The table shows that it is

not unusual for a student to take a test two or three times before achieving the high-quality performance required for passing (90%). The tests are so comprehensive that, in order to score 90%, a good mastery of the material covered in the chapter is needed, even when the student has taken exactly the same test a few days earlier and afterwards discussed his errors with the instructor.

In the beginning of the experiment (Class of 1966) class meetings were held as scheduled. But it soon became apparent that the students were getting "out of step," so that too few students were finding any given topic sufficiently pertinent to the work they were doing (or putting off) to make class meetings fruitful. After six weeks of regular class meetings with steadily decreasing attendance (since no effort was made to coerce attendance) no more such meetings were held, although some extemporaneous lectures were given to small groups. With the Classes of 1967 and 1968, class meetings were discontinued as soon as the students voted to use the auto-graded mode. The most efficient plan would probably be to hold class meetings for the first three or four weeks, while the students are relatively "in step." But the students find the no-class feature one of the big attractions of this mode of operation. Some of the disadvantages of not having formal class meetings may not have showed up in this experiment, because nearly all the students were also enrolled in a laboratory course which met six hours a week with the same instructor. So there were many opportunities for student-instructor consultation.

The advantages and disadvantages observed in the operation of the course are discussed later.

COURSE EVALUATION

A course-evaluation questionnaire was filled out by the students at the end of the course. The returns were anonymous and it appeared that the students felt quite free to express their feelings and suggestions. In 1966 there were seven returns from a class of ten, and in 1968, nine from twelve. In 1967 the students got away before the questionnaire session could be arranged. For the two classes covered, the total enrollment was 22 and the number of questionnaires completed was 16.

Table 2 summarizes the answers obtained. To encourage the students to think about each question, the answer blanks on the questionnaire were scrambled as to positive, neutral, and negative reactions. In Table 2, the answers have been rearranged for easier analysis.

The two classes are not tabulated separately because they did not differ greatly in their opinions. The Class of 1968 indicated a somewhat more positive attitude: surer of mastery of the

TABLE II — COURSE EVALUATION
QUESTIONNAIRE

Questions	Answers			Suggested Number Checking
	<i>yes</i>	<i>perhaps</i>	<i>no</i>	
Do you feel that the material covered in this course will be of value to you in your career?	8	6	2	
Did you find the course work interesting?	<i>most of it</i> 9	<i>some of it</i> 4	<i>little</i> 3	
Did you feel that you have a good understanding of the material?	<i>most of it</i> 9	<i>some</i> 7	<i>little</i> 0	
How did the amount of material covered compare with other two-credit courses?	<i>too much</i> 11	<i>average</i> 4	<i>too little</i> 1	
What do you think of the text book used?			<i>yes</i> 8	<i>no</i> 6
	interesting		11	3
	easy to understand		14	2
	well organized		3	12
	too condensed		1	10
	too varied			
How did you feel about this course plan at the beginning of the semester?	<i>enthusiastic</i> 5	<i>willing</i> 8	<i>reluctant</i> 3	
How would you feel about it now?	<i>enthusiastic</i> 0	<i>willing</i> 14	<i>reluctant</i> 2	
How well do you think this plan would work on various class levels?		<i>well</i>	<i>poorly</i>	<i>average</i>
	Soph	0	12	4
	Junior	1	5	10
	Senior	7	3	6
How well did the problems assigned cover the important material in the book?	<i>well</i> 5	<i>pretty well</i> 9	<i>poorly</i> 2	
How well did the exams test your mastery of the problem topics?	<i>well</i> 5	<i>pretty well</i> 8	<i>poorly</i> 3	

material and of its career value, less critical of the textbook, and not so impressed with the excessive amount of work demanded. On the other hand, they felt more keenly the danger of "putting-off" work, and were more critical of the tests. This modest improvement in attitude, displayed by the third group compared to the first group, may be in part due to more experienced handling of the course by the instructor. Also, the third group had two outstanding students and a well-developed group spirit.

DISCUSSION

The amount of material covered in this course varies from student to student. ("A" students study more chapters than "B" students; "B" students more than "C" students, etc.) because

TABLE II — (continued)

Check any of the statements below which represent fairly closely your experience in this course:

	Number Checking
I spent a lot of time studying the text book on the topics covered by the problems.	12
I read the whole chapter carefully.	8
I also read some chapters not covered.	2
I tended to ignore the book and get problem solutions from other students.	5
I did the problems mostly on my own and really understood them.	11
I tried to memorize the problem solutions instead of understanding them.	5
I felt that having the course organized this way saved time for me and let me do my best.	5
I expected to pass more exams, but found the latter chapters were too hard or took too much time	3
It was easy to put off working on this course.	12
I would have done better if there had been some deadlines at (monthly) intervals.	6
I didn't like having to plan my own work.	2
I felt that some students had an unfair advantage.	5
The instructor didn't seem to care whether I worked or not.	8
The instructor was not very helpful when consulted	3
What factors hurt exam effectiveness?	
too easily memorized	6
not enough time	4
asked wrong things	2
hard to interpret	2
students cheated	2
too mickey-mouse	1
poor surroundings	0
too much time allowed	0
Write-ins (one each):	
had to be memorized	
many topics not covered	
had to memorize numbers	
rather picayune	
too much detail in correction	

this seems to be the simplest way to organize an auto-graded course. This disadvantage would be harder to accept if the course were not at the end of the curriculum. On the other hand, comprehension level is maintained high for all students ("90%"). In the conventional, lock-step course, there is a standard "coverage" and the students are graded according to their comprehension level. Actually, both plans have arbitrary limitations: 90% is not perfect, and there are always more topics which could profitably be included in the standard coverage. For many a student, the feeling that he has achieved high-level com-

mand of a topic would be a welcome change from the feeling of failure or mediocrity he gets in many of his courses. It is certainly more realistic training for engineering practice to develop a comfortable facility with a limited subject area than to get a haphazard acquaintance with a broader field. The coverage achieved in this course is considered by the author to be excellent for the two semester-hours credit given. Of the 34 students who have taken the course, only four (grade D) have stopped short of consideration of optimum-temperature progression in homogeneous reactors (C-level), while thirteen (A and B), also got work in heterogeneous reactions.

Retention of skills developed is, of course, as important as developing and demonstrating these skills. As in the usual educational situation, no measurement of retention was here attempted. However, the instructor was sensitive to indications of retention observable during a laboratory course the students take in the semester following the kinetics course. The observations have been favorable: when these students were assigned lab problems related to reaction kinetics, they showed quick recall of relationships, procedures, and even some details. Their attitude suggested confidence in their ability to handle this subject matter. It is reasonable that retention of skills learned in this type of situation would be relatively high, because the student has to "dig it out" for himself, and because, before leaving each unit, he is assured that he has a good grasp of the material.

The problems chosen by the instructor for the students to work on need to be "comprehensive," i.e., requiring a good grasp of the entire subject area to be "covered." It is not cricket to require the student to show more on the test than he had to do to solve the problems. On the other hand, the problems do not have to be neat and limited; the students have time to chew them over, seek out additional data, and resolve ambiguities (as in engineering practice). Some "old" problems can be used, since it is not essential that each student work every problem entirely on his own. This year, about half the problems in each set were new, and the rest were taken from previous years' sets. Some students attempt to memorize problem solutions borrowed from other students or found in "files" left by earlier students. However, students have testified that this approach is not successful. The problems are so involved that it is very difficult to write a 90% test without understanding the solution.

The tests need to be comprehensive enough that the student must either work through the problems himself or thoroughly study the solutions he borrows. The questions do not have to be pared-down to what an average student can

reasonably be expected to work out in 55 minutes. The student works on the problems before the test and he can take the test a second or third time if he has trouble assembling and organizing his answers in 55 minutes. So, even ambiguities in test questions, though to be avoided, do not have tragic consequences.

Repeated tests are not composed in the familiar "sampling" mode. This would result in students using information about the test questions as a guide to slighting important parts of the topic to the "covered." A typical test is shown in Table 3. Students are asked to show parts of

TABLE III — TYPICAL TEST

Exam on Chapter 5— Fall 1967

1. For Problem 11 (see problem statement below), derive the differential equation relating reactor volume to fractional conversion, and show the computations of the values of the constants used (in the integrated form of the equation) to find k from the experimental data.

2. For problem 18, derive the differential equation relating volume of reactor to fractional conversion, and explain how you proceed to compute the volume of the required reactor.

3. For Problem 19, derive the required equation and show all computations for the volume of (only) the back-mix reactor.

(Problem statements followed.)

some problem solutions in detail, while for others, they are asked to describe how the problem is solved. Students are often required to show the source of a model equation. This they refer to as "memorizing derivations," which they consider unfair. They also find that they can best get through a test in the limited time if they memorize a few key numerical values. Although many complaints result, it is doubtful that there is any lasting resentment. Students are so used to cramming for exams, that to memorize, ten minutes before a test, a few simple things is not much strain. The requirement that a test failed must be repeated in its entirety is the cause of the most-often expressed student irritation.

The repeated-test feature produces a steady stream of tests to be graded, and grading often must be done with unusually high precision, in order to decide between a 91 and 89 without seemingly arbitrary or inconsistent. Of course, a test paper which has two really bad flaws can be checked off quickly, as can a well presented repeat test by a student who nearly made it last time and has been shown his error. It is even more essential than in conventional courses that tests be graded promptly — within 24 hours at

the most. This may require some careful planning by the instructor, such as limiting the time when tests are given so that he is free to correct them immediately. No "final exam" was given in this course, as there seemed to be no role for it.

The role of the instructor in an auto-graded course is different from that in a conventional course. It is expected that the student will think of the instructor as a source of useful information. The instructor can promote this attitude by giving out hints and checking students' problem solutions, as well as by explaining mistakes on tests. This consultant role contrasts with the need a student sometimes feels to "snow" his instructors (impress them with his knowledge while not revealing gaps in his command of their subjects.) The instructor of an auto-graded course is in a good position to find out what a student needs help on, and what he can do on his own. In order to use this opportunity effectively, the instructor needs a firm grasp of his subject matter and the ability to listen to students. When meeting a rapid succession of students with questions on a wide range of topics, he has to "shift gears" a lot. If they come in groups, he may find himself operating in a "time-sharing" mode.

When the instructor finds himself treating the same, often trivial, question over and over as each student comes upon it, it occurs to him that if he were giving a lecture course he would need to discuss the point only once. He can minimize his losses here by individualizing these encounters and using them to build up rapport. For topics that are sure to cause trouble for a lot of students, a mimeographed hand-out can be prepared. With the excellent textbook used in this course, only one such text supplement has been prepared. (It deals with the question of changing density of the reaction mass in a flow reactor.) The instructor of an auto-graded course spends more time "consulting" with students, but less time preparing and delivering lectures (and wondering if he is "getting through" to the students.)

The auto-graded course rather than promoting competition between students, stimulates the formation of study groups. Leading students get considerable opportunity to help other students, and strengthen their own learning in the process. A certain amount of working together on problems is good training for engineering practice, and in an auto-graded course, is not the threat of the instructor that it sometimes is in conventional courses.

The effect of this course format on a student's motivation is of course difficult to generalize. Ostensibly, the student is working for a grade and whatever that means to him. Although this does not sound very commendable, perhaps in the

present-day college context it is not in any real sense a regression. And, it would seem that it would help a student focus his energy to know that the grade he chooses is his when he demonstrates the required learning. The students indicated on the course-evaluation questionnaire that they put more effort into the course than they would expect to put into a two-credit course.

The pressure on the student in this course was rather even and continuous, compared to conventional courses, where there are sharp peaks before six-weeks exams and low periods between them. This low-tension atmosphere, while it was an advantage for some students, was the most important factor limiting the general success of the course. Many students put off working on the course so much that they came out with C-level achievement where they could, with wiser investment of their time, have attained the A level. (Some of these students may have been waiting for their leaders to move, and when they did move, couldn't keep up.) To combat procrastination, the instructor supplied each student with an Experience Table at the beginning of the course, and offered additional copies occasionally. He also drew attention to the deadline established for the end of testing. (This deadline was extended for one student because of illness and for one who was working hard on a D.) More effective ways of reducing student procrastination are still being sought.

The self-pacing feature, which permits procrastination, is on the other hand a strong motivating factor for some students. They are very impressed by the prospect of finishing the course well before the end of the semester which is entirely possible and has been done by some students.

Undoubtedly a lot is gained, in the way of good feeling about the course, by the freedom from weekly schedules, class attendance, and the final exam. Of course, one can not say how much this

pays off in faster, more lasting learning. If most courses were self-pacing, the advantages of novelty would fall to the lecture-exam courses. Ideally, the different courses in a curriculum should be operated in a wide variety of formats, each in an optimal way for its particular objectives. Cheating is not an important factor in this course, because the test questions are not secret and tests failed are repeated without significant penalty, nor is any advantage gained by not giving credit for help received. Ethical problems are raised by a largely undesirable behavior pattern known as "leaching," where an unconfident student will attach himself to a leader, or one with a channel to a leader, in order to obtain more information about the problem solutions than he is able to contribute. There is little the instructor can do about such a situation. The students tend to work out arrangements so that all involved gain something.

CONCLUSIONS

All the students in this auto-graded, self-pacing course demonstrated high-quality command of a reasonable amount of chemical-reaction-engineering skills. There were no failures, and only one early drop out. Forty percent of the students received A or B grades for work beyond the level considered satisfactory for the number of credits given. There is every reason to believe that their retention of this learning will be superior. The amount of material covered varied with the student, and would have been greater for some if the tendency to procrastinate had been suppressed. Students generally agreed that they worked harder than in most courses. A theoretical advantage of the course is that the student behavior encouraged (if not uniformly obtained) bore a strong resemblance to that of a practicing engineer.

OPTIMIZATION R. R. HUGHES

(Cont'd from p. 116)

4. Equipment Design

The final category is really just good equipment design. To obtain detailed pictures of the makeup of packed bed reactors, the nature of internal baffles in stirred tanks or the exact form of heat exchanger bundles, a good designer must optimize in terms of some minimal cost or maximum-performance criteria. Each type of equipment requires its own special treatment for optimization, so that a general treatment of equipment optimization is not really desirable. In many cases, however, it may be possible for the designer to make use of some of the optimization algorithms.

MODEL FORMULATION

How then do we go about formulating a process design model? The calculations normally involve six distinct steps, once the desired decision variables have been chosen and the necessary objective and constraint functions have been identified.

- **Stoichiometry.** The heat and material balances for all major pieces of equipment are normally involved in any process design. According to the problem, it may be desirable to make the material balance on a mole, weight, or volume basis. In some cases, for example in certain types of refinery problems, it may be possible or necessary to treat the stream in total. But, normally, at least a nominal set of components should be identified and separately balanced.