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Problem Solving in PSI

The Personalized System of Instruction, devised by Keller[1] and Sherman in the 1960's, is a course format that has been winning wide acceptance among university teachers in the past few years.[2,3,4,5,6] In this article we indicate the main advantages that we see in the format, the modifications that we have made to adapt it to our needs, and some of the results obtained by using a modified PSI format in two engineering courses.

a problem about problem solving

Engineering is concerned with problems and problem solving to an extent that is often unrecognized by persons outside the field. As a commission on undergraduate education at the University of Minnesota recently declared, "The central purpose of engineering is to pursue solutions to technological problems in order to satisfy the needs and desires of society."[7] Small wonder then that the typical engineering course focuses on technological problems and their solutions.

Traditions generally link us to an honored past; they make life more predictable and make people feel more secure. However, some of the traditions of engineering education also carry disadvantages. It is traditional for a teacher of engineering to give his students exercises, tests and exams that consist largely of problems to be solved. It is traditional for the typical student to succeed in solving these problems only partially or intermittently. The teacher's tradition for marking student papers is to give "partial credit" for solutions containing some kinds of errors and for attempted solutions containing some correct features. The "partial credit" makes it possible for a student to graduate as an engineer without ever having produced a correct solution to a single problem and makes it impossible for engineering teachers to certify that their graduates can, in fact, solve problems. Thus, these traditions cause a short-fall in the preparation of engineering students for solving technological problems.

the standard psi format

The use of a course format that incorporates a mastery requirement offers one way of reducing this shortfall. News of course formats of this type reached us through workshops held by the McGill Centre for Learning and Development and the American Society for Engineering Education. When we made our adoption decisions, in the spring of 1971, the PSI format appeared to be the most highly developed course format having a mastery requirement. It had already been used successfully for psychology, engineering and mathematics courses at several different universities. Therefore, it was at least plausible that we would be able to use it successfully for problem-oriented courses in chemical engineering.

The main features of the PSI course format are:

1. Each student proceeds through the course at the rate that he chooses, that is, the course is self-paced.
2. Each student must show mastery of a module of the course before he may work on the next module.
3. A student who does not show mastery in a test may take retests on the same module without penalty and without limit until he passes. The several test forms that are prepared for each module are different.
4. Each test paper is evaluated on the spot as soon as the student completes it. At the time of the evaluation, students who do not pass are given personalized tutoring and directions for remedial study.
5. Most of the formal instruction is given by means of texts and printed notes.

Self-pacing and the personal contact between a student and the teacher or his assistants are features that come along with the mastery feature and increase the attractiveness of this format.

Keller's papers[1,8] show that the standard PSI format is based on a conditioning theory of learning. According to this, a PSI course should be divided into a large number of modules to permit a high frequency of positive reinforcement. In principle, the tests should employ the techniques of programmed instruction, such as prompting, shaping and fading, so that the student perceives the questions as being relatively easy. Under these conditions, the student has a high probability of passing any particular test and being reinforced thereby. In sum, the standard PSI format minimizes the aversive aspects and maximizes the reinforcing aspects of the testing situation.

Skinner[9] has pointed out that programmed instruction and similar techniques eliminate both problems and problem solving. Therefore, while these techniques are useful for teaching concepts and rules, they are not suitable for exclusive use in courses that focus on problems and problem solving. In terms of the Bloom taxonomy of educational objectives[10], engineering problems usually test objectives of the *analysis, synthesis,* and *evaluation* levels. Reports on PSI courses[3,4,5,6] suggested that the instructional objectives had been restricted to the *knowledge, comprehension* and *application* levels. Thus, there were substantial reasons for modifying the standard PSI format for our courses.

a modified format

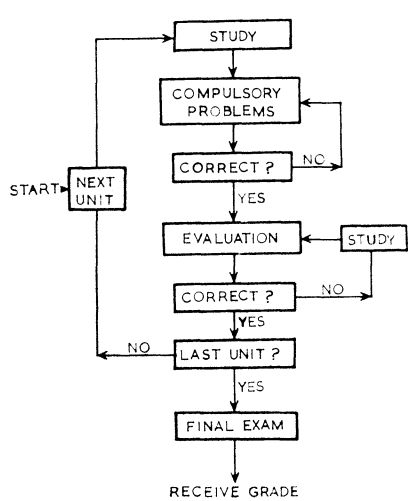
We combined the main features of the standard PSI format with a strong focus on problems and problem solving to produce a modified format for our courses, Chemical Process Principles I (CPP) and Chemical Reaction Engineering (CRE). Both courses have been taught twice, so we have been able to use several variations.

The materials for each of the two courses are arranged in the standard PSI way[1,3,5,8], with instructional objectives, study guides, practice problems, and evaluation tests for each module. We prefer to use fewer modules than Keller and other PSI practitioners recommend. The contents and sequence of the modules are derived from course learning hierarchies of the type described by Gagné[11]. The student's path through one of our courses is described in *Figure 1.* Evaluation test periods are available to students several times per week; we have used frequencies as high as 8 and as low as 3 per week. To minimize the stressful and aversive character of testing, these periods have been made as long as practical (2 or 3 hours). There are four possible outcomes of an evaluation test:

1. *No errors.* The student receives the objectives and study guide for the next module plus some personal, reinforcing remarks from the teaching assistant or teacher who judges his paper.
2. *Conceptual errors.* The student must take another test on the same module. The evaluator must find the student's errors and help him see the difference between his work and an approved solution. The student is referred to remedial material in the text or notes and, if he has difficulty after this, he is encouraged to ask one of the teaching assistants for help.
3. *Numerical errors only.* The student is told that he has an error. If he finds the error himself and corrects it within the test period, he passes the test and if he cannot find and correct it he is tested again.
4. *Miscellaneous faults.* Occasionally test questions are ambiguous, the solutions take more time than expected, or sometimes an error in a student's solution cannot be found within a reasonable period of time. In cases such as these, the student is permitted to continue on the same problem at the next testing period. His test paper is kept by the staff and returned to him for continuation.

Figure 1

Flowsheet of Modified PSI Format in CPP



In contrast to the standard PSI format, one class meeting is held every week in CRE and every second week in CPP. The class meetings are used to give information about the course format and class progress and for various kinds of lectures. Lectures have been used to illustrate the application of the course material outside of the usual industrial context, to highlight the important points in specific modules, and to teach systematic approaches to solving several classes of problems.

In both courses, students are required to do some additional work besides the evaluation tests on the course modules. In CPP, the students must solve home problems which are longer and more comprehensive than those given on evaluation tests. The papers are evaluated and recycled to the students until the solutions are judged to be correct. In CRE, the additional work consists of design problems that are assigned to groups of students. The solutions are judged as to the freedom from obvious errors and the attainment of the design objectives. Final examinations and term papers have also been used.

In sum, the modified PSI format combines an emphasis on problems with a mastery requirement and testing conditions that are relatively non-aversive. The frequency of reinforcement is reduced compared to the standard PSI format.

results with psi

The remainder of this paper presents the answers to a number of questions we are frequently asked about our courses. The answers are based on records of student progress, our opinions and student opinions as expressed through anonymous questionnaires. The statistical data reported are for the courses as given in 1971-72 when there were 34 first year university students in CPP and 25 second year students in CRE.

What was the Grade Distribution in our Courses?

Of 59 students in the two courses, 42 finished all of the modules, 7 finished all but one and 8 finished all but two. Only 2 of the students failed to complete the minimum number of modules required for a passing grade. As final course grades we gave 31 A's, 17 B's, 9 C's and 2 D's.

Did the Students Really Learn More with PSI than with the Traditional Format?

We are confident that these grades reflect increased mastery of course objectives. Circumstantial evidence for this comes from the final examination marks in CPP where the average grade was 10% higher than for a comparable examination given a year earlier with the traditional format. The low mark "tail of the distribution" was clearly reduced with the PSI version of the course. In CRE there was no appreciable difference in the examination marks between the traditional system and the PSI system. We did note, however, that in our courses the students did not cram for the final examination as they usually do. We attributed this to the fact that the examination could change their term grade by only one level and they knew in absolute terms what these grades were. Achieving similar or slightly better results under these circumstances may portend longer retention. There is some evidence that PSI courses do yield increased retention.[12]

In our courses the students solved a number of problems completely. In CPP all students except two solved at least 12 problems since the grade C required the completion of 7 units and 5 home problems. In CRE all but one student solved 13 problems: 9 units plus 4 home problems. These results are in sharp contrast to those achieved in the traditional engineering course.

More direct evidence of learning comes from student responses to an anonymous questionnaire. They were asked if they had more confidence in their ability to solve problems in our subjects than for other subjects of similar complexity. Of the 55 students responding, 46 indicated "yes" or "definitely yes."

An important skill used in the solution of engineering problems is the ability to find and correct your own errors. Because of the mastery requirement on the unit tests, many of the students acquired this skill. When asked in CRE if they learned to do a better job of finding and correcting errors, 22 of 24 students said, "yes." Our views and the views of the students coincide — they have substantially improved their problem solving skills.

Could Students Cheat to Avoid Mastery?

The PSI system is set up to minimize the incentive for cheating by reducing the consequences for failure. An additional safeguard is built into the system, however. During any one test session, no more than one half of the class takes tests. Since different tests on the same unit and tests on different units are taken simutaneously, the chances for examination room cheating are greatly reduced.

Could Those Passing a Test First Help the Others Pass the Test?

We do not believe that discussions between students about tests are necessarily harmful. Since we used anywhere from 3 to 10 test forms for a unit, the passage of specific information from one student to another could be dangerous as well as helpful. However, since there is a possibility of a communication chain from the leader to the others in the class, we asked the students whether they could guess or find out what was going to be on the test. Of the 56 students responding, 52 said "seldom" or "never." Data corroborating this are presented in *Figure 2* where the average number of tests taken is plotted against the number of units behind the student completing a unit first. If specific information helpful in doing the tests were passed from one student to another, the line would slope downward, i.e., it would be beneficial to lag behind the leader. Since the opposite trend is shown even for one unit behind the leader, it appears that students did indeed master each unit.

A sociometric study of the CRE class[13] reached similar conclusions when considering the performance of groups of students who habitually worked together. It was found that the class consisted of 3 cohesive groups of 3, 5 and 8 students and 9 students who were either isolated or fringe members of one of the groups. Membership in a group did not reduce the average number of tests taken per unit nor did it change the picture suggested by *Figure 2*. In short, the students appeared to master the material.

What Strategy Did the Students Adopt in our Courses?

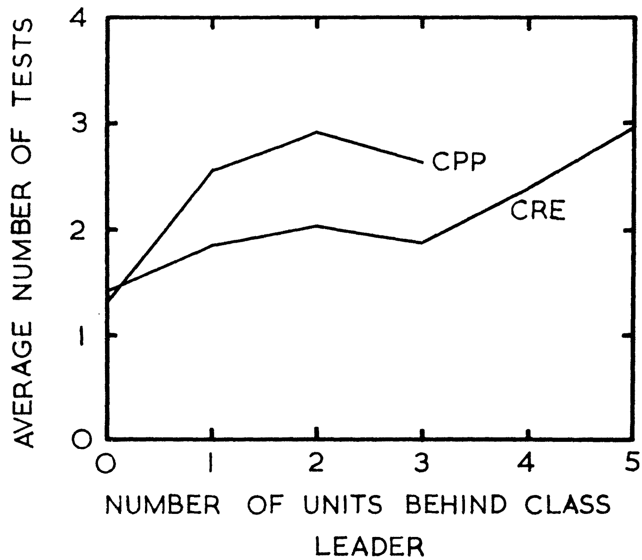
We expected that student strategies in a PSI course would be different from the strategy of maximizing partial credit frequently used in traditional courses. In CRE a study of student strategies was made while the course was in progress.[13] There were four fairly distinct strategies.

1. Minimum tests — 4 students
2. Maximum speed — 8 students
3. Steady pace — 6 students
4. Irregular pace — 7 students

The final examination results of the students adopting the minimum tests strategy were the highest in the class. The

Figure 2

Average number of tests required to pass a module as a function of lag behind the first student to pass the module.



maximum speed strategy (passing one unit per week) meant that a student finished the course before the end of the term, but paid a penalty by taking some extra tests. The students adopting the steady pace strategy finished less than one unit per week — however, the slower pace was probably dictated by balancing the demands on their time rather than by a need to take more tests. Those progressing at an irregular pace took several "vacations" from testing followed by spurts of frenzied activity. The final examination grades of this group were lower than the average. Based on these data it would appear that the irregular pace strategy is not a good choice.

If our Students Mastered the Material, Why Didn't They All Get 100% on the Final Examination?

The reason that they did not get 100% lies in the very nature of a problem. Each problem presents new difficulties to the problem solver in much the same way that each hole presents new difficulties to the golfer. The performance you expect of our students is analogous to expecting a golfer to break par every time. Even Jack Nicklaus cannot do this. The characteristics of problems and the development of problem solving skills are described more fully in reference 15. Since problem solving is skill rather than knowledge, the appropriate question is "Did your students improve their problem solving skills?" As noted above, we believe that they did.

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