first derivative. Seven points thus probably represent the minimum number that should be used unless the data curve is very smooth. The other source of error is round-off error in the matrices themselves. Since the method is designed to be used by hand, the matrices have been limited to an accuracy of three significant figures, but this in turn means that accumulated round-off errors will limit the final answer to two significant figures. However, this should be sufficient for any situation in which manual data reduction itself suffices. For instance, we have found the technique well suited to making "quick look" analyses during the progress of a long experiment or rapidly evaluating day to day variation of an experiment.

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Physics Teaching by the Keller Plan at MIT*

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The Keller plan (a self-paced, student-tutored, mastery-oriented instructional system) has spread widely in the six years of its existence, but mainly in teaching psychology. The paper reports experience with the plan in introductory physics. The results are strongly favorable; students report that they learn material more thoroughly and more efficiently. Lectures are used sparingly and mainly for motivation. Students may take as many as 20 written tests in a semester without complaint. Sophomore tutors grade the tests on the spot and have proven to be extremely valuable. The instructor's role is not to broadcast information but to manage a system and to write the necessary tests and other materials, as well as to give personal help to individuals in unusual cases.

The conventional system of lectures, laboratories, recitations, problem sets, and examinations works pretty well for many physics students. For convenience and economy it is hard to beat, although the convenience is to the teacher and the economy is to the administration.

Nonetheless, many of us have sensed that there might be a better way to teach. We remember from our days as students how boring it was to sit through a lecture on something we understood perfectly well, or to wait out an explanation repeated for someone who was too busy writing down the previous remark to catch the current one. We chafed under the necessity of attending a nine o'clock class when we had spent the night on a term paper due in another subject. If we cut the class, we worried about what was covered. Even when we felt we knew the material, we often worried about the exam, for we remembered other occasions when we had walked into an unexpected question and realized too late that our understanding had only touched the surface.

Most innovations in physics teaching have naturally tended to center on things of interest to the physicist. A new apparatus to demonstrate conservation of angular momentum, a cheaply producible accelerometer, a beautiful film showing examples of geometrical symmetry, a way to
draw Lissajous figures with sand, and, on the theoretical side, a simpler way to derive a difficult result—all of these things are inherently interesting to the teacher as physicist (and to his physicist colleagues).

But there are other constituencies which the innovationally inclined teaching physicist must serve—constituencies which have different needs. One such constituency is the students. At a minimum, the students want to learn what will gain them access to useful professions, whether that be grades or understanding. Another, the administration, wants this to happen at minimum expense; and if an external funding agency is paying for the educational innovation, it would like to be assured that the new thing is effective and exportable.

Evaluation in these terms has been difficult. The instructional effect of ingenious apparatus, of a new film, or even of a new textbook depends on the instructional system into which it fits. Each of those innovations is, in fact, only a component of a system, and it is, finally, a whole system which succeeds or fails.

The purpose of this paper is to report our experience at MIT with an instructional system designed to exploit what has been found about learning from the perspective of “reinforcement theory.” Before describing this particular system, let us consider instructional systems in general from this point of view.

The concept of an instructional system is not useful until we distinguish between teaching and the transmission of information. It is obvious that one does not teach violin playing merely by transmitting information to the student about how to play the violin. The student must do his part, and the teacher must evaluate and respond to the student’s efforts. The student is an active element in a process, not merely a receiver of information. In verbal learning (as opposed to skill acquisition) the “receiver model” of the student appears to work better, but that is mainly because the other phases of the learning process are not usually made explicit. They are still there.

In the view taken here, learning is a three-step process: presentation, response, and consequence. Presentation is the sending of signals (including “course content”), whether by lecture, textbook, film, or live demonstration. Response is what the student does after the presentation. Thinking about what was just said is a minimal response; working a problem is a more visible one. But a response dies out unless it is followed by a favorable consequence at least occasionally. After thinking, one suddenly understands. After working a problem, one sees that the answer is right. After taking a test, one gets an A. Occurrence of the consequence completes a cycle.

To design an instructional system is to arrange a sequence of these three-element cycles in such a way as to optimize learning. This can be done at various levels of detail. At the finer end of the scale there is programmed instruction of the short-question, quick-answer, quick-confirmation type. On the coarse end there is a semester plan of lectures (presentation), final exam (response), and course grade (consequence), which constitute only one giant cycle. Most good college courses fall somewhere between these extremes.

It seems important to avoid both these extremes. The small-frame program tends to get monotonous; a student needs more variety in his response mode if his interest is to be sustained through a period of months. Besides, such small-frame programs are expensive to create and tend not to take advantage of the self-teaching skills many college students have acquired in high school. The “one-big-final-exam” course, on the other hand, is notoriously ineffective. Most courses have at least a mid-term exam and if the grades are fed back to the students, this completes a first half-term cycle. The instructional system to be described below has its most prominent cycles about one week in length.

The system I now wish to describe has been called “self-paced study,” but self-pacing is only one feature. It has been called variously “personalized” and “programmed” by its inventors, Fred S. Keller and J. G. Sherman. Perhaps the best choice is to call it the “Keller plan” in honor of the senior member of this team, a distinguished psychologist who was for many years chairman of the psychology department at Columbia University.

A visitor observing sessions of a Keller-plan course finds it hard to see what is going on. He wants to know how often the class meets and what hours the students are required to attend.
There is a puzzling bustle and confusion in scheduled rooms at scheduled hours. People are busy talking, writing, walking around. There may be more than one room in use; one where people are writing, another filled with pairs of people talking. The instructor may be talking with one or two students, or he may be idly reading a newspaper. Students are continually entering or leaving with no particular notice taken of the fact.

What is going on is basically this: The subject matter of the course has been divided into units of work, in our practice about one week's work of a conventional course. For each unit there is a study guide and a set of perhaps four short tests, hopefully equivalent. The instructor has bought his ease by preparing these materials in advance.

A student works from the study guide, which states what he should learn and suggests a way to go about it. When the student feels that he can do what he is supposed to be able to (such as work problems of a given type, explain certain apparent paradoxes, give an account of certain historical developments), he asks the instructor for a test. He writes out his answers in the classroom and takes the paper to his tutor, an undergraduate who attends class sessions regularly for this purpose and who is responsible for 10 students. The tutor examines the paper and marks it (after discussion with the student) pass or fail: If pass, the student gets the next unit's study guide from the instructor. If fail, the student must work further on the same unit and try again.

The apparent confusion in the classroom reflects the fact that some of the students there are just studying alone, some are taking tests, and some are consulting their tutors on difficult points. Sometimes the instructor is asked to review a paper on which the student and tutor disagree. Sometimes he substitutes as tutor himself.

Some students may be working on Unit 9 while others are still on Unit 2. The pace is up to the student, within limits. Some students make rapid progress in spite of failing many tests; others are more cautious and never fail, although their pace is slow. (The usual equation "fast" equals "good" breaks down.) What counts is progress, no matter how fast or slow. Failures on unit tests do not affect one's course grade.

If the visitor to the course comes on one of the rare days when lectures are given, he will notice that attendance is small, but that those attending are awake and alert to participate. He may be surprised to hear that the day's lecture is intentionally "off on a tangent" to the main course content. In fact, students are promised that attending the lecture will not help them gain a higher grade. Even more strange, the students may have had to earn the right to attend the lecture by having passed a critical number of units. There may be only one lecture every two or three weeks.

Depending on the subject matter, the student may have a variety of other things to do besides studying from books and papers. He may have facilities to view film or film loops. He may be able to check out take-home kits for doing experiments. But, in each case, he decides whether to engage in the activity according to whether he thinks that to do so will help him achieve the unit's objectives, as stated in the study guide.

I first read of this instructional system in an article by Keller which was detailed enough to enable me to try out the scheme with 20 students in the spring term of 1969. The subject was 8.02, meaning physics (8), second semester (02), which includes special relativity and an introduction to electromagnetism. We used the same texts as were used in the regular course; only the method was changed. I broke 8.02x (x meaning the experimental section) into 18 units of work and for each unit, I wrote a study guide and four tests. The guides were between two and 10 pages double-spaced. I stated objectives as operationally as I could in a few lines, and I made up a "suggested procedure" consisting of reading, working a few problems, answering a few questions, and sometimes viewing a film. In areas where my conception of the subject matter differed from that of the text, I wrote some prose discussion, and often I made up short programmed sequences of questions.

Of the 1000 students enrolled in 8.01 in the preceding fall term, about 600 heard my brief announcement of an experimental course, about 150 came to that evening's meeting at which the course was described, and 100 applied for the 20
places I could offer. I tried to choose equally between those who were bored with the "slow" pace of 8.01 and those who were hopelessly left behind by its "swift" march.

It has become cliche in educational innovation to report that "the students were enthusiastic." I enjoyed giving the course. I found that I got to know the students much better. I knew they were learning more because I had in hand the 18 tests which each student wrote out by the end of the term. I discovered difficulties and had to repair several units. How the students experienced the course is reflected in their comments, some of which are quoted below.4

The success of 8.02x in that spring term 1969 led me to try 8.01x in the fall, again with only 20 students. My colleague, Edwin Taylor, decided to offer 8.04x at the same time. Jay Walton of Civil Engineering offered a computer course 1.00x as well. Each of these new Keller-style courses were kept small so as to give us a chance to prove our study guides. If something were not good enough, we could teach it "by hand" if necessary. In the following term (spring, 1970) we gave 8.02x again to 100 students, under the leadership of Daniel Kleppner and Berol Robinson; and Edwin Taylor again gave 8.04x, this time for 75 students. At this writing (fall, 1970), all of 8.01x, 8.02x, 8.03x, and 8.04x are available, and 8.05x is being prepared.

Obviously we are pleased. We can see students working hard and enjoying it. We know from previous experience that they are learning fully as much as students in the regular versions of these courses.

We have not collected comparative test data. (Others who have tried the Keller plan2,5,6 and have published such data find an inverted normal distribution of grades: more A's than C's.) Such comparisons are debatable and usually do not convince skeptics anyway. Instead, let us report the comments students make about our Keller courses. In addition to students' responses to questionnaires, we have Freshman Performance Evaluation sheets which each freshman must fill out twice a semester for each of his courses. Although they are asked to rate themselves on these sheets, many freshmen comment on the course as well as on their own performances.

We report these comments by category, since it is of great interest to see what features of the course students see as important, positively or negatively. First the global judgments:

A rave review:

**FANTASTIC.** I wish all my courses could be like this. I personally enjoy this more than any other course I take. It is more satisfying than anything else. Every department in the Institute should be required to offer self-paced options in each subject.

I am very glad I took part and would enjoy taking similar courses not only to learn the material but also to examine the educational aspects of the things worked. I'm interested in education and this is really great. Keep up the good work—but remember you're writing for dummies—not fellow professors.

Freedom, understanding, without pressures for problem solving skill.

Rather than the 8.01 emphasis on solutions, 8.01x places its emphasis on understanding, with solutions coming as a logical extension.

You'll have to pay me to take 8.02 when 8.02x is available.

Here is our only global bad review:

8.01x is a teach-and-learn course and turned out to be as inefficient as all its competitors. The human mind does not learn efficiently or permanently when it is told something, read something, deduces something, etc.

This last comment probably refers to the highly structured nature of the course. The subject is laid out in serial order of topics, and the student is advised just how to study for each one. This is not to everyone's taste, but the objection occurs more often to teachers than to students. So far I have had only two students out of about 50 who felt this reaction strongly. I advised these students to switch back to the regular class. In fact, neither of them did so. One continued with us and then enrolled in the succeeding 8.02x; the other got permission to pursue independent study, in which he performed very well.

The specific feature of our experiment which received most comment was freedom of pace.

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Ben A. Green, Jr.

I go at my own speed; I have no pressure put on me by other people; people don't try to make a jackass out of me when I don't know something.

For the student who wishes to study without being paced by an instructor, it is ideal. If I don't finish an 8.02 problem set by the due date, that is too bad, but in this course, one can procrastinate ad infinitum, if necessary. I have just taken a two-week vacation from physics but am not behind at all.

I think one of the benefits of self-study is the freedom to set your own pace and define your own interests. Regular courses tend to bring the horizons of a topic too close, hemming you in.

If I were in 8.01 and had troubles...I'd be behind by the time I got it figured out. Here I'm not, and when I catch onto something I don't have to wait around for others to hold me back.

Time to dwell on a subject if I wanted to.

I found I had gone quickly through the first few units and was able to spend more time later on parts that were unclear.

Closely related to freedom of pace were comments focusing on the freedom to study when and where one wishes.

I like to work on them [units] when not in the mood for too much work. I am especially glad to be free of problem sets and lectures.

Not the regular hum-drum. It was nice to be able to do it when you wanted—not when you were supposed to.

Free work schedule was the best thing.

Not getting up at 8 for lecture, no problem sets (to submit formally), or deadlines.

The tutors were valued:

... tutors—most effective part of program (if tutor is good).

(Most of our sophomore tutors have been very good.)

They [tutors] are very helpful when self is insufficient for self-study.

A comment on what we call "mastery as a criterion for advancement":

This type of program is just what is needed for P-F grading. If you don't know it, you get an F, but have a chance to keep at it until you get a P; then, you know you know it—and no half measures, either.

Another student put his finger on the response-consequence phases of the learning cycle:

The structure of the course is such that one can see the immediate effect of one's labors. Each unit test gives one a sense of accomplishment.

A prime payoff to the student from the self-paced format is that it makes his work more efficient:

My time was used more effectively.

I have gone through the material quite rapidly, not because there is less to do but because the presentation agrees with me.

I have not had to work at all hard, however, and sometimes doubt that I am learning as much as the people who spend endless hours on regular 8.01 problem set and reading. If all my courses were like this one, I would be learning more and spending less time on useless homework assignments.

When I see the other students on the [dormitory] floor slaving over 8.01 problem sets three nights a week, and not getting too far at that, I take pity.

This efficiency results from a number of factors, but most prominent among them is probably the fact that the objectives of each unit's work are defined explicitly. The student does not spend time on other matters unless he is interested in them for their own sake. While this saves a student time, it may cost him the many other things he might have learned if he had chosen topics more randomly. Some students complain about this. Actually, a student still has freedom to explore in self-paced study and we encourage him to use it. We do require a specified minimum which is easy to acquire. If this minimum is interesting, other exploration becomes self-rewarding.

We come now to the most troublesome aspect of self-pacing: What if the pace is too slow? We have all had the experience of working better under deadlines than without them. When the problem sets do not have to be turned in pre-
cisely on Wednesdays, it is easy to put off the work. In the students’ words:

I feel I could have done better and delved more deeply into the material had I been self-motivated. But because of the nature of the course and pressure from other subjects, I did only an adequate amount of work.

The temptation to loaf when on the self-paced program was too much and I fell units behind. However, in the past week or so, I have made up most of the work.

Procrastination is a problem only with some students. The average rate of work in our freshman course 8.01x in the present term can be seen in Fig. 1, which shows the total number of tests passed versus time (class days) in the fall term, 1970. If everyone eventually passed all the units, the curve would coincide with the straight line at the right-hand side of the graph; and if everyone passed units at a steady rate, the curve would be the straight line. Thus the gap between the curve and the line is a measure of either procrastination or (toward the end of the term especially) withdrawal. The curve shows that, on the average, the freshmen keep up well.

It is interesting to compare the two sophomore courses 8.03x and 8.04x in this respect. Edwin Taylor, who ran 8.04x in the fall term, 1970, was not particularly concerned with the procrastination problem. If a student wanted to finish the work during the following term, that was okay. In my 8.03x, on the other hand, I announced that “Ts” would be hard to get, and that grades would be given on the basis of work accomplished. Furthermore, I (a) published a recommended schedule of dates of passing units which would yield a steady rate of work, (b) made admittance to “fun” lectures contingent on having passed units, and (c) offered early final exams for students who finished the units early. (The final is required in order to get higher than a B grade. The passing schedule contained a normal pace and an accelerated pace, the latter finishing in time for the early final.)

The results of these different policies is shown in Figs. 2 and 3, which show the test-passing history of 8.03x and 8.04x. The schedules were published on Day 9, which may account for the jump in the 8.03x curve at that point, although that was also the day just before the first fun lecture.

**SOME QUESTIONS AND ANSWERS ABOUT HOW THE COURSES ARE RUN**

**How many tutors are needed?**

We find that a tutor should be responsible for about 10 students, certainly no more than 12. If there are fewer tutors, then the waiting time to get a test graded gets too long. If there are more, a tutor can get too bored waiting for a student to talk with.

**How is time scheduled during the week?**

We have tried five 1-h periods, three 2-h periods and two 2-h periods (during which the tutors and instructors are available in the study area). A 1-h period is wasteful, since no tutors are needed until students have had time to write out their tests. Also, failure costs a day’s delay. With a 2-h period, one has a second chance to pass a test, and the load on tutors tends to even out over the period. We have settled on three 2-h periods.
**Fig. 2.** Total tests passed by class in subject 8.03x vs class days, fall 1970. The students were sophomores.

**How do you keep track of what students are doing?**

We have tried several ways. Taylor keeps a record book, a loose-leaf notebook with a page for each student. A notation is entered here of the results of each test and sometimes of other events such as consultations and special arrangements. A picture of the whole class's status is available from a wall chart showing when each student passed each unit. In 8.02x we once used a computer for record keeping, which made it possible to print out a variety of graphs and summary statements. We have since settled for just a wall chart and a status graph for each student.

In all of our x courses, we keep a file folder for each student, which contains his completed unit tests. These tests are raw data for any analysis we choose to make.

**What can you do for students who procrastinate?**

This is a little complex. Keller advocates ignoring them, on the ground that surely they already know what is expected of them. If they choose not to work, that is their privilege. Certainly if someone has been prodded to work all his life, it may take him some time to learn to work without the prod. If we prod him some more, he will never have a chance to learn self-motivation. In our experience, this policy is very hard on the instructor. He wants his group to do well not just for their sakes, but for the sake of the experiment. This puts a pressure on him to get in touch with slow students and to bully them on. Our best results in avoiding large-scale procrastination without nagging have been gotten by offering short-term rewards for passing units (admittance to fun lectures), long-term rewards (admittance to early final exams), having a clearly announced policy that I's are hard to get, and giving guidance in setting paces (calendars).

**What about students who finish all the work early?**

We stand ready to suggest further reading, etc., but we are perfectly content to see them play tennis or watch girls. They have mastered the content of the course, and if further work is not attractive to them, they should not be penalized for their speed. We have recently allowed students in 8.01x and 8.02x to take the final examination early, although some prefer to wait for the regularly scheduled time.

**Fig. 3.** Total tests passed by class in subject 8.04x vs class days, fall 1970. The students were sophomores.
How are grades determined?

We have tried various ways to assign course grades. (Unit test grades are always pass/fail, of course.) In freshman courses, we have set the grade according to mid-term and final examination scores only. This has several theoretical advantages: it takes cheating pressure off the unit tests, it takes the tutors out of the judging business and leaves them purely as coaches, which improves the student–tutor interaction. On the other hand, it puts a great burden on only two examinations. The courses are graded P–F (for freshmen), however, and experience has shown that students who pass the unit tests always pass the final exam. The student who freezes on the final in spite of knowing the material is apparently rarer in our self-paced courses than in others. In sophomore course 8.04x, there is no final and grades are given according to the fraction of the term’s work completed. This works well in practice and it seems to give the students a feeling of being above such “childish matters” as final exams. And there are no finals to grade!

What about cheating on the unit tests?

Each unit has four test forms. It would be possible to give a student any one of these at random as a first test. Thus to cheat he would have to have advance information on all four forms of the test. But we don’t do this. We just give form 1 first, form 2 (if necessary), etc. In the freshman courses, the unit tests do not count toward a grade, so there is no motive for cheating. There has been no evidence of efforts to cheat in the sophomore courses either.

What goes into a good study guide?

A study guide should tell the student what the unit’s objectives are and how to accomplish them. This could be as brief as

Objective: Know what is in Chapter 13,

Procedure: Read it,

but one can do better than that. We like to state the objectives for a week’s work in about half a page, single-spaced.

A good procedure is the product of trial and error by the instructor. He must guess what reading is required, what is the minimum set of problems a student needs to work, what outside reading would help, and he must write pro-

grammed or other explanatory material to patch over the weak places in the text. Then he must listen to students who try out his procedure and modify it in the light of their experience until finally it works—works for enough students that he is willing to teach the rest by hand.

A seduction to be avoided is to test on juicy items you cover in the procedure which are not also covered by the objectives. Remember, a student should not have to go through your procedure. He may know the material already, and he should be able to judge this by reading the objectives only. Once you discover that you have sinned (you get an irate complaint from a student who skipped the procedure legitimately) you must decide whether you really want everybody to learn the cute item in the procedure (and must say so in the objectives) or you didn’t really mean it (and must take it off the test).

How do you handle a laboratory under the Keller plan?

Unfortunately, MIT does not have a full-scale laboratory for the introductory physics sequence, so we cannot answer from personal experience. However, Keller’s original course in psychology did have a laboratory, as do several of the physics courses described below. One simply keeps the laboratory open for some scheduled hours and lets anyone come in who wants to work. There is no reason why unit tests should not cover things learnable only from laboratory experience. Swartz (Stony Brook, see below) frequently specifies performance tests using actual equipment. Postlethwaite’s botany course at Purdue, which is nearly self-paced, is also centered around laboratory experience.

What kind of student does best under a self-paced regime?

This is a research question we cannot answer well as yet. We hope to develop a test which can predict success under this mode of work. There are, at least, some common-sense things to ask. Does the student have a record of putting things off? Has he succeeded at some kind of independent study? Does he have a clear idea of why he is taking the course?

It may not be worthwhile to try to answer this question. In courses where the students had no alternative to the self-paced version (Arizona State, Portland), they seem to do as well as if
they were all volunteers (MIT). It might be that volunteers are self-selected because of the opportunity to procrastinate!

**How do you recruit tutors?**

So far it has been sufficient just to announce the opportunity to serve by means of bulletin boards and some class announcements.

**But what happens if half the courses in the school go Keller-style? Are there enough tutors?**

An interesting possibility has been explored by Sherman of Georgetown University. Sherman served as tutor for the first 10 students to finish the first unit. They all accept an invitation to become tutors for the rest of the class! There was no pay and no extra credit, but they all served cheerfully and faithfully.

**How does the Keller plan compare on cost of operation?**

This depends, of course, on what you compare it to. To teach 100 students, we believe one should provide one instructor (faculty) and one course manager (teaching assistant), both paid. There should be about 10 tutors, who are paid in academic credit in most of our courses. If the course has not been given before, the instructor must spend some time preparing study guides and tests; if he is happy with some particular textbook he can prepare skeleton study guides rather easily. This time is a one-time cost incurred whenever the course is materially altered. Space is a bit of a problem. A collection of three or four rooms totaling about 2400 square feet would serve 700 students if it were available 42 h per week. (Add 600 more square feet for a laboratory room.) Compared to a 1000-man lecture section with no recitation leaders or laboratory instructors of faculty rank, a Keller-plan course is expensive. But compared to 25-man faculty-led sections, it is very cheap. (Should one count the saving of student time and effort?)

**More on earning the right to attend lectures.**

It is interesting that almost everyone who has tried some form of self-pacing in university courses has eventually instituted some deadlines. As Bill Moore puts it,

We need to differentiate between self-pacing and individual pacing. That is, we need to maintain the notion of individualized instruction, but at the same time provide some means of controlling the pacing in a way which is best for the individual. A purely self-pacing procedure tends to nurture procrastination in some students.

A generous minimum pace requirement exerts pressure only on the dilatory student, however, so a sense of freedom remains for the majority. The Summerhill alternative (wait indefinitely for the student to act) causes too much administrative bother.

Yet it is possible to get an adequate rate of work from a class without punitive deadlines.

I have already mentioned the tricks we introduced in order to combat procrastination in our latest trial of 8.01x and 8.03x: the calendar of dates for passing units in order to keep on the minimum or the accelerated pace (not required, however), the early final exams, the no-Incomplete grade policy, and the restricted admittance to lectures. This last one deserves more comment.

In the fall term of 1970, I finally amassed the courage to try Keller's idea of requiring a certain amount of work from a student before admitting him to lectures. In 8.03x, for example, one must have passed Unit 6 in order to be invited to the second lecture of the course. This strikes many people as very odd, if not illegal! What saves my conscience is that the material covered in the lecture is definitely not essential, or even helpful, to mastery of the required course content. Once I had a guest lecturer talk on the physical basis of perception in a course on waves and vibrations! Those who came had a treat, but those who could not were not directly penalized.

**Will students actually work to be able to attend a lecture?**

We missed a chance to prove that they will. The data of Fig. 2 for 8.03x shows a jump in rate of test passing on the ninth day of the course, which is the day just before the first lecture. However, that is also the day after each student was given the schedules referred to above. Some students have volunteered comments such as "I want to pass two units today so that I can go to the lecture."
Why do students come to lectures at all?

They come for fun, to see a professional in action, and because they still can’t believe they don’t have to. (If half of the class attends, that’s doing pretty well.)

How can you keep out students who are not qualified?

We do not stand at the door and turn people away. We just tell the location of the lecture only to the qualified students. I doubt that even this subterfuge is necessary, however.

Doesn’t grading only on mastery degrade grades? Shouldn’t a man who learns quickly get a higher grade than one who takes three times as long?

This is a matter of personal philosophy which is widely debated. I take the position that so long as you make yourself clear, you can make the grade mean what you want it to. I choose my dentist by how well he works, not how fast he learned. Why not apply the same standard to physics students?

How can a sophomore possibly be wise enough to be a tutor?

Two factors: (1) The sophomore need not know everything just to grade a specified set of tests. He works from a limited agenda. (2) Sophomores turn out to be better tutors than graduate students in general, perhaps because they are fresher from the tribulations of learning the material at hand. Also, the tutor’s work is subject to review, appeal, and reversal by the instructor although appeal is seldom necessary.

Don’t students rebel at taking so many tests?

Not at all. Students have passed tests and returned asking to take another test on the same unit. Tests in the context of a Keller-style course are an opportunity to show off what one can do. The penalty for failure is mostly internal disappointment, not external punishment. And one always has another chance.

Why can’t you teach 1000 students as easily as 100 in a Keller-style course?

The limit is due to two factors: (1) The instructor must handle situations which the tutors cannot. He is a court of appeal, and must not be overloaded. (2) He must also oversee the tutors. A tutors meeting with 100 tutors is absurd. One must be able to discuss individual students at meetings and must help tutors individually with difficulties in the material. With adequate supporting faculty, of course, one can expand.

OK, it works at MIT, but will it work anywhere else?

How about Stony Brook, Bucknell, Portland State, University of Texas, Georgetown, Arizona State, C. W. Post College, Florissant Valley Community College, and Western Michigan.

OTHER EXPERIENCE WITH SELF-PACED STUDY

The Keller plan has spread in a few years from its beginnings in one psychology course at Arizona State University to other schools and other subjects (although the published accounts of such courses are not yet numerous). Since we are physics teachers, I would like to describe some other instructional systems now being used in physics teaching at several universities—systems which share two features of the Keller plan: self-pacing and mastery as a criterion for advancement.

Bucknell University

Bucknell has had support from the Carnegie Foundation for several years to experiment with a “Continuous Progress Program,” which has been implemented in the departments of physics, biology, psychology, philosophy, and religion. Students work at their own paces on units of about two week’s work. There is a laboratory open for students whenever they want to use it. Unit tests are available when a student is ready for them. Tests are composed by computer, randomly sampling a bank of test items and are graded by machine, the results being communicated to the student within a week of his taking it. The instructor handles all tutoring. The physics program is directed by Owen Anderson.

A report on the Continuous Progress course in biology, philosophy, and psychology has been published by Moore, chairman of Bucknell’s department of education, and his co-workers. They found that students in the experimental course compare favorably with those in regular recitation sections both in terms of accomplishment and attitude. They also see great value in having sequences of several courses available in this form to permit students to complete more
than one course per semester (whence the name “Continuous Progress”).

University of North Carolina

The quickest entry into self-paced study I know of was made by Marvin Silver, who divided 16 chapters of Halliday and Resnick into eight two-chapter units and made up a set of 50-min four-problem exams from the problems at the end of the relevant chapters. He required perfect solutions to at least three problems on an exam for a pass. He acted as tutor for all students and also gave optional lectures on “the Physicist’s World” and sometimes presented his colleagues as guest speakers. Silver reports that student morale was high, that he enjoyed the course greatly, and that he won three new majors away from chemistry! Grades were determined by total number of tests passed with an option to raise one’s grade by a final examination. He gave 27 A’s and 9 B’s in a group of 45 students. This success has led others at UNC to try the same technique.

The State University of New York at Stony Brook

A plan very similar to Keller’s was designed by Clifford Swartz for an introductory course. Physics 161, a text and lab course for nonmajors, has a large room open continuously in which students get help, take tests, and do experiments. Participating faculty tutors keep scheduled tutoring hours in their offices, and graduate-assistant tutors man the course headquarters. Course objectives are detailed in handouts. Tutors give tests, written and oral, on the spot and sometimes include a requirement to demonstrate competency with equipment. Grades are given for effort, achievement, or whatever the tutor thinks best, but are accompanied by a paragraph on what the student accomplished. (The registrar was persuaded to establish suitable files for this purpose.) While detailed results on this new program are not yet available, the plan seems to be enjoyed by both students and faculty.

Portland State University

After Phil Pennington heard Keller describe his “personalized system” at the fall 1968 meeting of the Pacific Northwest Association for College Physics, he decided to try it out with 34 students in the physics segment of a Basic Science course sequence which covers biology, chemistry and physics in a two-year program. Most of the students were freshmen interested in the health sciences.

Pennington writes:

The most notable reaction was in attitude toward physics of most of the students. Previously, physics had been something to get over, like a bad cold. Now there was considerable hallway discussion of physics; my office hours became jammed with students asking about physics; and my library of related books—Gamow’s One, Two, Three, Infinity, Steinhaus’ Mathematical Snapshots, Schrödinger’s What Is Life, for example—became much in demand. (I allowed the students to check them out.) Even several issues of Science were checked out. This activity did not abate even after students had completed the units, and it was going strong after the final exam (several of my books were checked out for the summer).

THE KELLER COURSE AS TEST BED

Once you have a Keller-style course in operation, you suddenly find yourself equipped with an educational laboratory. The course is a culture medium for new teaching ideas. You can try something new with a single unit, give it to the first few students who come to that unit, get their reactions (including test performance and personal impressions) and then change the thing in time for the next wave of students one week later. This is a very fast feedback cycle compared to the typical semester-long course.

It is very appropriate that the first students hit you first, since they will find the most serious flaws in your material. The minor things will not stop them. Then the second wave will be protected against overwhelming obstacles and can report to you the next less serious problems.

A SUBVERSIVE FEATURE AND AN INHERENT LIMITATION

The Keller plan is destined not to spread quickly. If one lays out in study guides exactly what one expects of students and how they are to accomplish these goals, then one has specified the course in much greater detail than one
usually does even in a syllabus. This has two important effects.

First, one's teaching becomes subject to audit. How often has it been asked how one can evaluate good teaching when teaching is such a private act between teacher and student? But when most of the teaching goes on in the medium of print, the teacher's privacy is gone (though the student's privacy is enhanced). The teacher is now open to detailed criticism. The result can be a little frightening. Keller says he feels practically naked when he gives his materials to a colleague.

The hope is, of course, that good teaching will be recognized by one's colleagues. If differences of opinion on specific pedagogical techniques arise, they can, in principle, be settled by a comparison experiment. For the long run, the more the teaching process is captured in observable form, the easier it is for the teacher to grow in knowledge and skill.

The second effect is that it becomes very hard for anyone other than the author to use a given set of materials. In the standard course, an instructor can use a textbook flexibly, leaving out sections and introducing other material. Through his lectures a teacher can also introduce topics in his own style and thus make the course his own. This is harder to do when lectures are no longer the main channel of communication and the approach to each topic is enshrined in print. The result can be that the instructor no longer feels sufficiently involved with the course—it's no longer his baby. If the adopted-child effect cannot be avoided, you cannot publish good study guides successfully.

There may be some ways to avoid this difficulty. One is the “Chinese restaurant” approach: You write study guides like a catalog from which the instructor can pick the objectives he judges important for his students. With each objective is listed the suggested procedure for accomplishing it. The instructor composes his own study guides by taking one objective from column A and so forth. Unfortunately, what is left out in Unit 3 may be required in Unit 7. Another alternative (due to Ed Taylor) is the “add-the-eggs” approach: the study guides are written with a little bit missing, which the instructor adds.

The barrier to proliferation still must be overcome, but I do not have the answer at hand.

CONCLUDING REMARKS

The Keller system of instruction is far from ideal. It accepts a dogma now under attack in higher education: The teacher should select for the student what he is to learn once he is enrolled in the course. It denies that having the student bathe in the aura of the charismatic teacher is the most effective means of having him learn physics. There are subjects in which the precise content of the syllabus is not as important as the influence an outstanding personality can have in a seminarlike encounter. The Keller plan is not a good candidate for such subjects, in my opinion. But if there are specific things to be learned, the Keller plan will do the job effectively and most students will enjoy it. A statistic which measures quantitatively how much our students enjoy it is that 90% of those who have taken on Keller course have applied to enroll in another.

Note added in proof: To receive a newsletter about Keller-plan courses, address J. G. Sherman, Psychology Dept., Georgetown Univ., Washington, D.C. 20007. For information about a conference on this topic 16-17 Oct. in Cambridge, write the author. Invited and contributed papers will be presented.

An early report on 8.02x, “A Self-Paced Course in Freshman Physics”, B. A. Green, is available as Occasional