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ABSTRACT
This study was concerned with the production, organization, utilization, and evaluation of an individualized program of instruction in introductory college physics. Key features of the Program included an open-learning center staffed and equipped with a variety of instructional materials, and a self-paced testing arrangement utilizing a number of repeatable mastery examinations. Characteristics of the 125 students randomly selected for the study were ascertained with a background questionnaire and a physics and mathematics pretest. Achievement in the course was determined by the number of units successfully completed. Questionnaires were administered to determine the average amount of study spent per unit, the values assigned by students to particular instructional materials, and student attitudes toward the course. Grade aspiration and mathematical skill proved to be the entry factors having the greatest influence on achievement. Learning efficiency was mostly influenced by sex, the student's anticipated difficulty level of the course, and his possession of physics-related concepts and physics-related mathematical skills. Staff and student attitudes toward the course were favorable, and student achievement improved. (Author/MH)

AN EVALUATION OF STUDENT ATTITUDES, ACHIEVEMENT, AND LEARNING EFFICIENCY IN VARIOUS MODES OF AN INDIVIDUALIZED, SELF-PACED LEARNING PROGRAM IN INTRODUCTORY COLLEGE PHYSICS

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A. Introduction

Recent advances in technology have made it possible to offer a wide variety of instructional alternatives within a given course. This has resulted in greater flexibility in course format allowing program developers to better satisfy the diverse interests, abilities, and learning styles of students. Unfortunately instructional strategies and modalities are often adopted in carte blanche fashion solely on the intuitions or prejudices of a course designer or instructor. The key elements which have been lacking in the development of most instructional components are systematic procedures for evaluating the relative merits of each component in terms of its contribution to the achievement of both cognitive and affective objectives.

This study was concerned with the development and evaluation of individualized self-paced instructional methods and materials in a course in introductory physics at Cornell University during 1972-73.

B. Purpose of Study

The central aims of the research reported in this study were:

1. To develop procedures for investigating the relative merits of each instructional component for different types of students.
2. To determine those factors which seem to have the greatest influence on a student's use of instructional components, his achievement, his rate

of progress, his attitudes, and his disposition toward a meaningful learning set.

3. To contribute to the understanding of some of the conditions and processes of learning in general.

C. <u>Theoretical Assumptions</u>

The theory of David Ausubel (1968) suggests that individualizing instruction can facilitate meaningful learning thereby enhancing the quality and improving the efficiency of concept acquisition. Ausubel's central concern is in the area of cognitive reception learning. His major argument is that the learning of new knowledge is facilitated if the knowledge can somehow be associated with ideas already possessed by the learner. In this way new learning has greater meaning to the learner and can thereby facilitate the acquisition of subsequent related knowledge.

Since the concepts possessed by learners on entry to a course of instruction vary widely, and since the conceptual framework of each individual is continually undergoing change as new concepts are added to cognitive structure, the process of associating new concepts with existing ones should be improved through the development of individualized programs of instruction. Since learning rates vary among individuals within each concept area, some form of self-pacing becomes a key ingredient in such a program.

Gagne (1970) argues for a dynamic assessment of capabilities during the learning process. In formal disciplines where the learning of subsequent concepts is strongly dependent on a firm understanding of certain prior concepts, a means of assessing the existence of these prior concepts is of particular importance. Pretesting prior to instruction coupled with some form of mastery testing following instruction can aid in making these assessments.

The principles of mastery learning, as discussed extensively by Block (1971) suggest that self-pacing can lead to high achievement for most students providing adequate learning time is allowed. High achievement should in turn result in a positive affective response thereby stimulating the learner toward further achievement.

In conducting educational research, affective and cognitive factors must be considered simultaneously in judging the relative value of a particular instructional component, method, or approach. For example, it would be foolish to insist that students perform a particular experiment on the grounds that it had proven to have high payoff in cognitive development, when there was some aspect of it which was fundamentally abhorrent to students. This is not to suggest that valuable learning experiences be abandoned solely on the grounds that they happen to be somewhat demanding; or that they require a fair amount of self-discipline, patience, or fortitude -- these virtures should be fostered in any curriculum. The value of a learning experience becomes questionable when it results in a prolonged frustration which tends to inhibit subsequent learning and leaves the student with a generally negative attitude toward the subject. While the difficult or demanding tasks may be unpopular during the learning process, if meaningful, they will usually be appreciated by students in retrospect at the end of the semester. Numerous studies of self-paced courses have reported significant gains in developing favorable student attitudes (Freedman (1973), La Brecque (1973), Anderson (1972), and Postlethwait (1972)).

D. <u>The Setting</u>

Over the past 5 years we have been active in developing individualized instructional methods and materials for a 2-semester introductory sequence at Cornell University. The course is large, involving between 20 and 30 staff and between 500 and 700 students. It is essentially aimed at students pursuing careers in life science including biology, pre-medicine, pre-veterinary, pre-dental, agriculture and other semi-technical areas, although some liberal arts students and others have also found it appropriate.

The physical facilities occupy a 10,000 square foot area with some 90 carrels containing audio cassette recorders, film-loop projectors, demonstrations and laboratory equipment, etc. In addition, there is a video-tape viewing room and several utility rooms. About half of the total space is occupied by a testing center which includes a central office, test-taking room, and three post-exam tutoring rooms.

The basic function of the learning center is to provide a wide variety of instructional alternatives which can be accessed whenever and as often as the student wishes. In this open and relaxed setting, students are free to work at their own pace and can obtain assistance from an instructor when problems arise in understanding difficult concepts or in operating laboratory equipment. The content of the course is organized into modules or units, nine in each term for a total of eighteen. One additional "unit," appearing at the completion of each term's work, involves a review of previous units and is followed by a retention exam. Most of the units are conceptually linked to others and are therefore studied in a recommended sequence. A few are more independent and may be selected for study at a variety of points during the semester.

In addition to the standard textbook used in the course, students are provided with a study guide containing a list of learning objectives, a list of recommended activities, laboratory instructions, audio-tape supplements, supplementary problems, programmed materials, and sample examinations.

The examination procedures used in conjunction with the open laboratory have evolved from the traditional large-group, non-repeatable, norm-referenced examinations held on announced dates during the semester, to a self-paced mastery mode with non-scheduled and repeatable criterion-referenced examinations. Thus there exists the possibility of comparing these two testing schemes.

E. <u>Instruments</u>

1. Background Questionnaire

The Background Questionnaire was administered at the beginning of the semester to all 700 students enrolled in the course. It was designed to collect information regarding the following:

a. sex, class, college and major;

b. background, achievement and attitudes toward physics and mathematics;

c. scholastic aptitude scores;

d. reasons for taking Physics 101, grade aspirations, and general disposition toward meaningful learning;

e. attitude toward various forms of instruction;

f. expectations concerning the interest and difficulty level of Physics 101.

2. Student End-of-Course Questionnaire

This questionnaire containing 80 items was administered to students as they completed the course and was designed to collect information regarding the following:

a. grade aspirations and general disposition toward meaningful learning in the course;

b. extent and type of preparation before taking the first exam on a unit;

c. general attitudes toward the course, format, and mastery testing schemes;

d. attitudes toward the various forms of instruction and the average time spent on each;

e. general interest and difficulty level of the course;

f. relative interest level, difficulty, organization, quality of experiments, and value of problem sets for each unit.

3. Staff End-of-Course Questionnaire

This questionnaire, containing 34 items, was completed anonymously by each staff member at the end of the semester and was designed to monitor the following:

a. attitudes toward the course, format, and mastery testing scheme;

b. estimation of the relative value of each of the various features of the course including their personal interaction with students.

4. Physics Pretest

To assess student entry knowledge of physics, the Dunning-Abeles Physics Test, published by Harcourt, Brace and World, Inc. was utilized. Of the 50 items included on the test, 8 were considered knowledge level items, 27 understanding level, and 15 application level. All students were given the exam upon entry to the course, and no time limit was set for completing the items. The items appeared to have acceptable validity, and the statistics obtained after administering the test appear in Table 1.

5. Mathematics Pretest

The Mathematics Pretest was designed specifically for monitoring mathematical facility in areas related to applications in Physics 101-102. All students were given the test on entry to the course, and no time limit was imposed. For analysis the questions were grouped into 3 separate sub-scales:

a. manipulation (16 items);

b. manipulation and interpretation (10 items);

c. interpretation (9 items).

Validity was checked with several local people in science education; for the statistics which were computed after administering the instrument, refer to Table 2.

TABLE 1

Summary of Item Analysis Statistics for Physics Pretest

Fall 1971

mean difficulty = .54

	Knowledge Subscale	Comprehension Subscale	Application Subscale	Total
no. of items	8	27	15	50
mean	4.8	15.2	7.6	27.5
standard deviation	1.5	4.5	2.7	7.6
reliability coefficient[2]	.39	.75	.66	.85

[2] Calculated from Cronbach's alpha (see Cronbach (1951)).

TABLE 2

SUMMARY OF ITEM ANALYSIS STATISTICS FOR MATH PRETEST

FALL 1972

	MANIPULATION SUBSCALE	MANIPULATION AND INTERPRETATION SUBSCALE	INTERPRETATION SUBSCALE	TOTAL
NO. OF ITEMS	16	10	9	35
MEAN NO. CORRECT	10.8	6.1	4.7	21.6
MEAN % CORRECT	67	61	52	62
STANDARD DEVIATION	2.8	1.9	1.7	5.0
RELIABILITY COEFFICIENT	.73	.59	.50	.83

10

6. Unit and Final Examinations

Achievement was measured through a number of unit mastery examinations, each designed to determine both the extent of general concept formation and the availability of subsuming concepts necessary for a smooth progression to higher order concepts. There were 6 equivalent exams written for each unit and each contained approximately 10 to 15 questions varying in type and range of difficulty. Each exam was expected to take approximately 30 to 45 minutes for the average student to complete. Only items which could be associated with a particular learning objective appearing in the students' study guide were used. The items were tagged with the corresponding instructional objective number or numbers to provide students with feedback; after taking their first exam on a unit, the student received a slip of paper (objective slip) indicating the objective numbers corresponding to the questions answered incorrectly. The passing level or the level of acceptable mastery was set at 80% for all exams. When students failed to pass any of the 6 exams on a given unit, one of the exams taken earliest was randomly selected and retaken. It was extremely rare that a student required more than 6 exams. The average number required to demonstrate mastery was 2.2 exams per student. Items were checked for validity by a physics professor and the author before use.

Unfortunately no reliability measures were performed on the exams. The fact that several students were able to pass on their first attempt on every unit serves as a fair indication of their overall reliability.

F. Analysis

1. Student and Staff Attitudes

Data was collected by means of optical scanning answer forms and statistical analyses were carried out on an IBM 360/65 computer.

Overall it was found that substantial gains were made in improving student attitudes through the implementation of the self-paced learning center format. See Table 3. Notable among these were the appreciation for the variety of instructional materials made available to them; the personal attention that students received from the staff in both the learning and testing centers; the friendly and relaxed, yet productive, atmosphere of the learning center; and the emphasis on learning quality rather than speed which was made possible through the self-paced testing arrangement.

General features of the course which can account for most of these reactions are probably the following:

a. Individualization

1) Students can select from a variety of instructional alternatives, those which seem to be the most effective for them personally.

2) Staff-student interactions are on a one-to-one basis; The student benefits from the instructor's attention to specific difficulties encountered by the student in understanding the material; the instructor quickly discovers the most common learning difficulties of his students and learns new ways of dealing with them through further interaction.

b. Self-Pacing

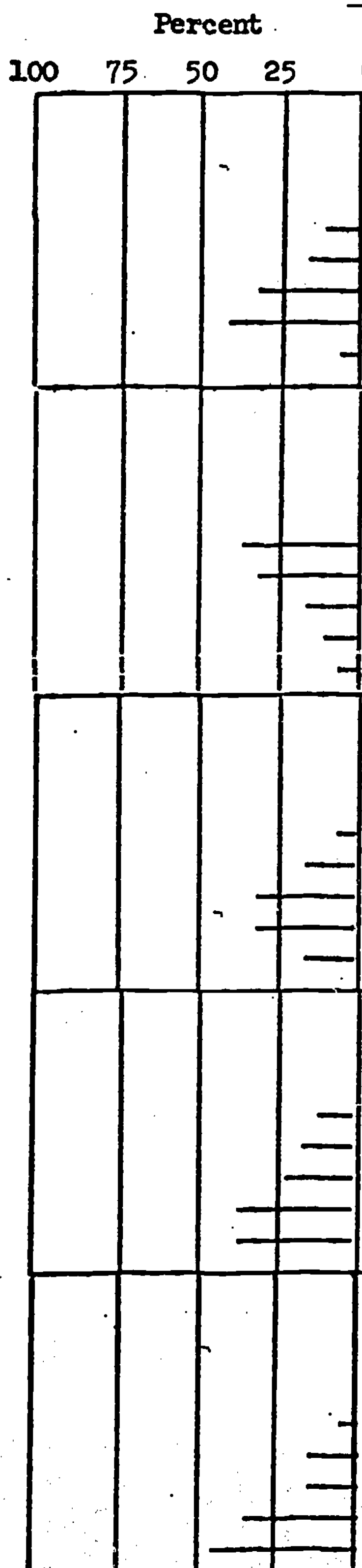
1) Students can work at times that are most suitable for them personally, and at a pace that allows for adequate internalization of concepts. The pressure to work under uncomfortable or unfavorable conditions is removed.

2) Students can repeat lessons as often as is necessary to achieve satisfactory understanding - including laboratory experiments.

TABLE 3

Percent Response on Student End-of-Course Questionnaire

Fall 1972 - Items as indicated



7. I have found the material presented in Physics 101 interesting.

strongly disagree
disagree
neutral
agree
strongly agree

11. A standard course format of 2 lectures, 2 recitation meetings, and 2 hours of laboratory would be more appropriate for this course.

strongly disagree
disagree
neutral
agree
strongly agree

12. Physics 101 has been more difficult than I expected it to be.

strongly disagree
disagree
neutral
agree
strongly agree

25. The advantages of the course format in Physics 101 far outweigh the disadvantages.

strongly disagree
disagree
neutral
agree
strongly agree

10. I like the flexibility offered by the format of instruction and testing used in Physics 101.

strongly disagree
disagree
neutral
agree
strongly agree

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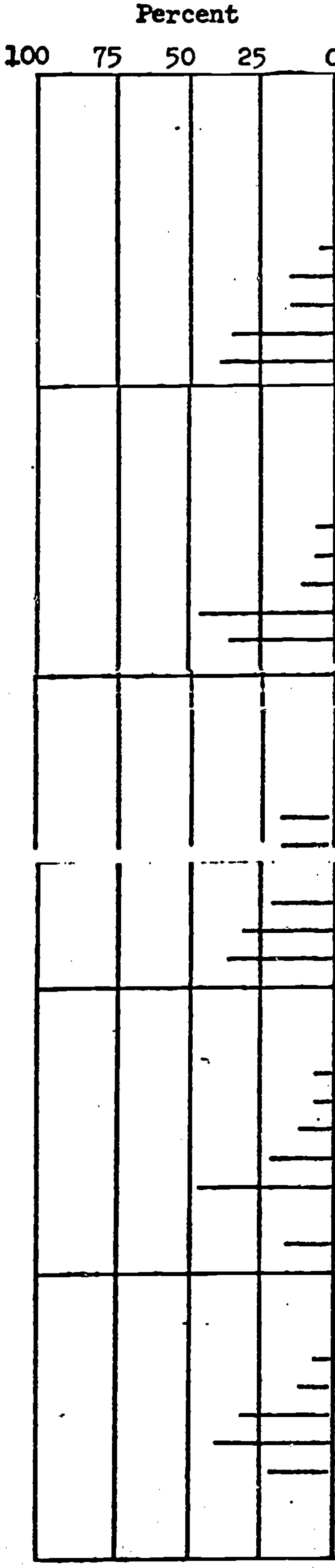
Table 3 (cont'd)



15. I have found greater challenge and stimulation from the self-paced testing arrangement than I would have found from a normal "one-shot" prelim exam arrangement.

strongly disagree
disagree
neutral
agree
strongly agree

24. I generally felt a sense of accomplishment after achieving satisfactory performance on each unit exam.

strongly disagree
disagree
neutral
agree
strongly agree

35. I feel I learned more with the self-paced "mastery" testing format than I would have if the course had "one-shot" scheduled prelims.

strongly disagree
disagree
neutral
agree
strongly agree

40. Going over exams with tutors in testing center.

not helpful
slightly helpful
somewhat helpful
very helpful
extremely helpful

did not use

50. Unit exams.

not helpful
slightly helpful
somewhat helpful
very helpful
extremely helpful

did not use

c. Integration of Learning Materials

The various instructional components are logically ordered so as to optimize conceptual development.

d. Mastery Testing

1) The pressures to rush or compete with other students are essentially removed. The principal source of motivation is derived from the satisfaction accompanying a series of successful and meaningful learning experiences.

2) Students do not have to accept defeat -- a chance to correct one's mistakes is always provided. Success is encouraged resulting in greater self-confidence, self-respect, and self-motivation. [A number of empirical studies have shown that a causal link generally exists between success and motivation. See Weiner(1965)].

With 25 staff working in the course, it was important to also consider their attitudes. Although the staff was composed largely of graduate physics teaching assistants whose primary interests were not in teaching, their reactions to the course were extremely favorable. See Table 4. They expressed a marked preference for the format of the course over the the more traditional format indicating that both they and their students derived substantial benefit from the experience - particularly with regard to the personal student-staff interactions.

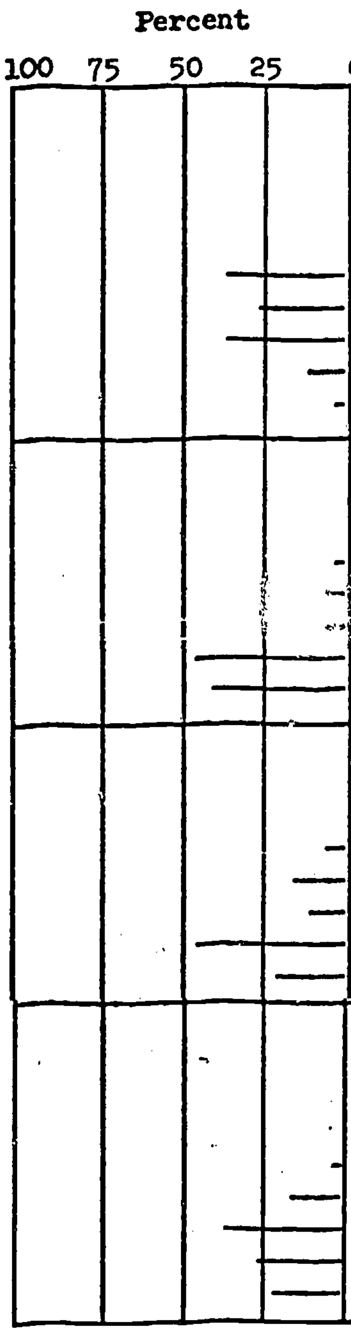
There is another dimension of positive affective spin-off generated by the kind of meaningful, successful, and humanistic learning experiences characteristic of this course: Long after the details of many of the concepts have been forgotten, there should remain a generally positive attitude toward the value and importance of the scientific enterprise, a general feeling of confidence in their knowledge and ability to solve difficult problems requiring sound analytical reasoning, and a general disposition toward intelligent and rational thought in connection with science related events in their daily lives.

TABLE 4

Percent Response on Teaching Assistant End-of-Course Questionnaire

Physics 101 - 1972

24 staff, 22 questionnaires returned



2. I would have preferred to be assigned to a course which operated conventionally with scheduled lectures, labs, recitations, and "one-shot" prelims.

   strongly disagree
   disagree
   neutral
   agree
   strongly agree

3. Overall I enjoyed working in the course this semester.

   strongly disagree
   disagree
   neutral
   agree
   strongly agree

4. I feel that working in the course has given me further insight into physical concepts.

   strongly disagree
   disagree
   neutral
   agree
   strongly agree

6. In general I feel that the operation of the course was educationally superior to a conventional course with lectures and recitations

   strongly disagree
   disagree
   neutral
   agree
   strongly agree

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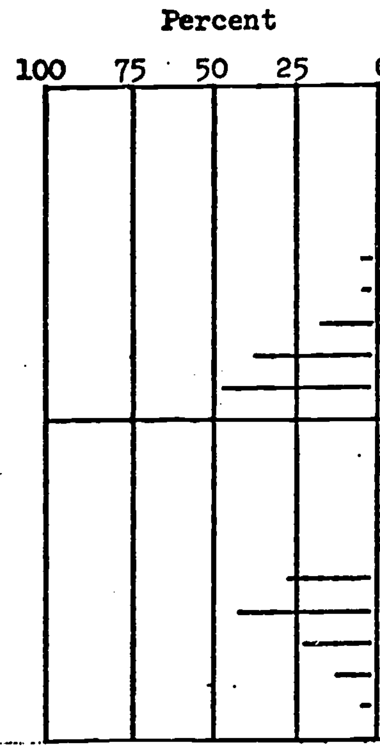
Table 4 (cont'd)



20. I feel that students are getting as much individual attention in this course as in most other courses on campus.

strongly disagree
disagree
neutral
agree
strongly agree

21. I have found the AT approach too mechanical and dehumanizing as compared with the standard format for a course of this size.

strongly disagree
disagree
neutral
agree
strongly agree

Concepts and procedures in physics and its related technologies are far too important in our society to remain absent from the average student's curriculum. It is the responsibility of the science community to bring to the average student's educational experience as much of the philosophy, content, procedures, implications, relevance, and significance of the field as is practical. For some students, this may mean terminating the differentiation of a particular concept at a somewhat superficial or introductory level. Yet if meaningful associations are made in the differentiation process, the new concepts, although somewhat shallow, should have value in enriching existing cognitive structure and hence serve to facilitate the future acquisition of related concepts.

It is hoped that from such efforts, students may develop a more positive attitude toward scientific endeavor and an improved understanding of its utilitarian as well as intellectual value.

2. Achievement

Final grades, which were used to indicate overall achievement, were determined by the number of units successfully completed. This included a retention "unit" for those completing all instructional units.

a. Mastery Compared to Norm-Referenced Grading Practices

To investigate possible differences between the mastery learning scheme and the more traditional single-attempt mid-term and final exam procedures, a semester of Physics 101, operating under the traditional plan is compared to a semester of Physics 101, operating under the mastery plan. See Figure 1. In the fall 1971 version of Physics 101 a norm-referenced grading system was employed: Scores on

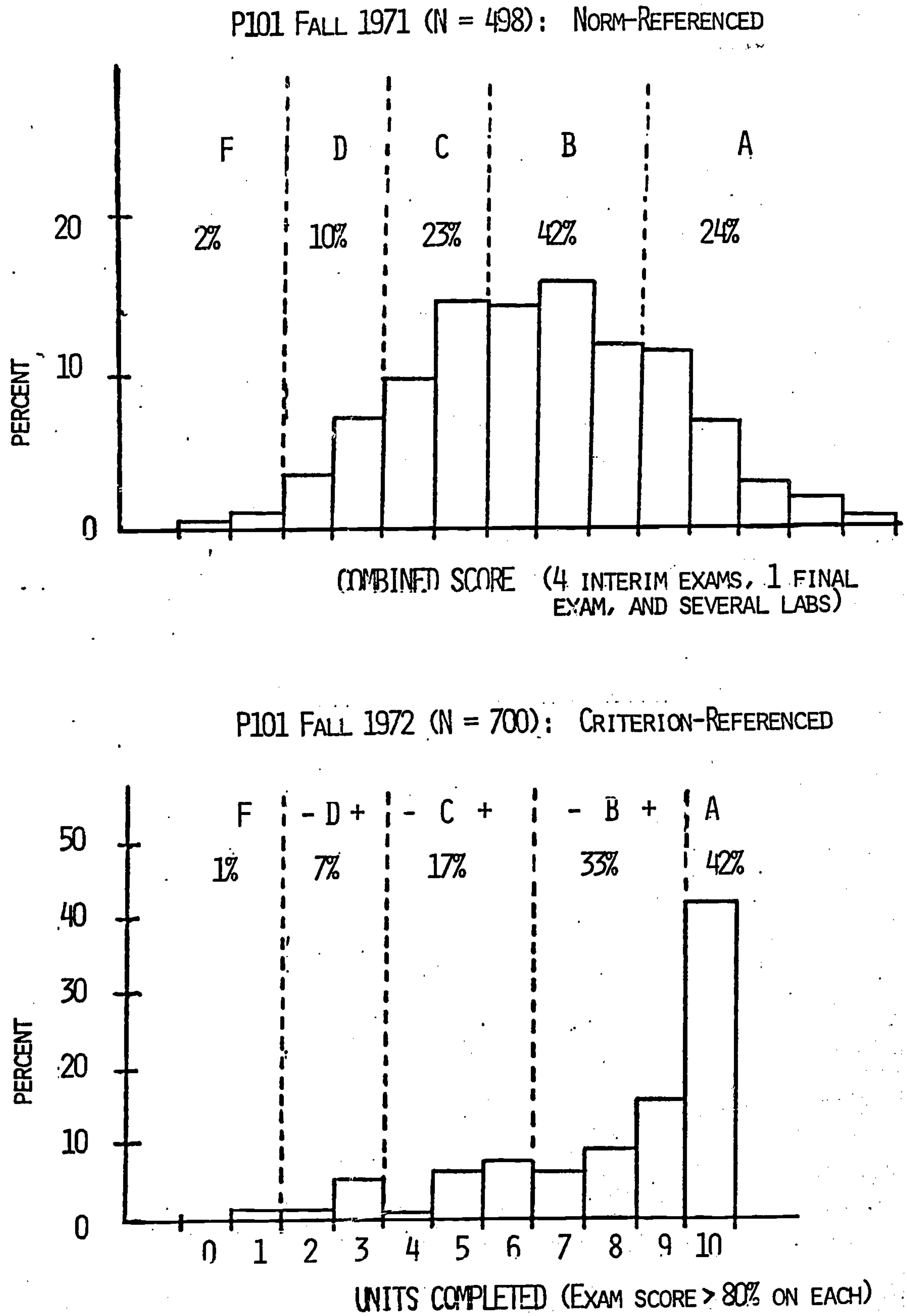


Fig. 1. Norm-referenced achievement vs. criterion-referenced achievement.

three interim exams and one final exam were combined for each student and final grades were determined by comparing each student's score to those of his classmates. A normal or gaussian distribution of scores usually results from this type of grading system. In the fall 1972 semester, a criterion-referenced (mastery) grading system was employed: The achievement level and its associated final grade were announced at the beginning of the term. Exams were repeatable and the time to achieve acceptable mastery was allowed to vary. The exams were also of equivalent difficulty as those used in the norm-referenced system. In the criterion-referenced system, final grades formed a highly left-skewed distribution indicating that the mastery procedures allowed a larger percentage of students to achieve at a higher level. This is consistent with other research reported on mastery procedures. [See Block(1971)]

b. Entry Factors

A Pearson correlation coefficient was calculated between achievement and some 40 entry variables obtained from the background questionnaire and pretests. Entry factors which were found to correlate substantially with achievement were grade aspiration ($r = .41$) and mathematical skill. See Table 5. Since mathematical skills were assumed and not taught per se in the course, it is reasonable to expect this result. In striking contrast to the norm-referenced system, such factors as scholastic aptitude, physics knowledge, and ability to solve physics problems correlated very little with achievement. These results lend support to the theory that if a sufficient variety of instructional aids are provided, if students are given sufficient time to learn a set of concepts, if they are given adequate feedback from examinations, and if

TABLE 5

Correlation with Final Grade in Mastery vs. Norm-Referenced System

	Mastery (Fall 1972) N = 700	Norm-Referenced (Fall 1971) N = 498
SAT (math)	.160	.500 [2]
SAT (verbal)	.243 [1]	.335 [2]
Math Pretest (Total)	.246 [1]	.528 [2]
Physics Pretest (Total)	-.003	.400 [2]

1 $p < .05$

2 $p < .01$

they are given the chance to correct their mistakes through retesting, then it is possible for the vast majority to achieve at a high level in spite of a number of entry deficiencies in cognitive structure.

c. Post-Entry Factors

During the semester, motivation appeared to be derived principally from grade aspiration, although the achievement success made possible by the self-paced testing arrangement also proved to bear a significant correlation with final grade. See Table 6.

A technique was designed to determine the relative achievement value of each of the instructional components for students differing in physics and mathematics pretest scores. Selecting a random sample of 125 students and using the results of the physics and mathematics pretests, the following four groups were formed for analysis: low physics-low math, low physics-high math, high physics-low math, and high physics-high math. A questionnaire was administered at the completion of the course to determine how the instructional materials were used by each student.

Of all of the instructional components, only experiments were required. It was the feeling of the course designers that some suggestions and recommendations should be made in the study guide but that the student should have the final choice in selecting media. The assumption here is that the learner is often the best judge of which activity is likely to be most effective for his own learning style. Giving the learner an active role in directing his path through the system also allows him to develop a stronger sense of control over his learning and helps to prevent what Silberman (1970, p. 201) refers to as "a prescription for training and not for education."

TABLE 6

Correlation of Post Entry Variables with Final Grade for

$r \geq |.25|$

Final Grade Scale:

		F	D-	D	C-	C	C+	B-	B	B+	A
1	2	3	4	5	6	7	8	9	10	11	12

15. I have found greater challenge and stimulation from the self-paced testing arrangement than I would have found from a normal "one-shot" prelim exam arrangement.

Scale:

Strongly Disagree				Strongly Agree
1	2	3	4	5

$n = 60$

$r = .25$ sig. $< .019$

16. I have generally had a greater tendency to procrastinate under the format of instruction and testing used in Physics 101 than I have had in courses using the standard lecture-recitation format with scheduled "one-shot" prelims and quizzes.

Scale: (same as #15)

$n = 69$

$r = -.38$ sig. $< .001$

To investigate the relative achievement value of each of the instructional components, the percentage of each student's total learning time devoted to each component was calculated and then correlated with final grade. A high positive correlation indicates that a high relative use of that component was associated with higher achievement and that a low relative use was associated with lower achievement. In other words, a high positive correlation indicates that the component offers high achievement value if used more extensively than the average; a high negative correlation indicates that more extensive use of that component would tend to offer less achievement value than a positive correlation and suggests that a student's time would perhaps be better spent on another activity. Table 7 shows the overall correlations of each of the instructional components with final grade, plus the same correlations within each of the four pretest groups. Not all students completed the End-of-Course Questionnaire and hence correlations could only be calculated for 69 students in the sample. Because of the small numbers in each group, the confidence intervals were rather large and it was not possible to make relative value distinctions between components appearing ar roughly the same vertical level in any one column of the table. The ability to do this would of course increase with a larger sample. Though the procedure used had severe limitations for the small samples, it did allow one to make general kinds of comparisons, particularly concerning those components appearing at the extreme ends of a column.

Components which seem to have positive achievement value overall, i.e., those whose confidence limits are above zero in the left-most column of Table 7, are programmed materials and integrated questions

TABLE 7

Correlation of Final Grade with Percent Time Devoted to Each Instructional Component

r = correlation coefficient
E = confidence limits (68%)
Item = (see Key on p.

Ordinal Position ↓	OVERALL n = 69			LP-LM n = 18			LP-HM n = 21			HP-LM n = 9			HP-HM n = 21		
	Item	r	E_1 / E_2	Item	r	E_1 / E_2	Item	r	E_1 / E_2	Item	r	E_1 / E_2	Item	r	E_1 / E_2
15	SGPM	.46	.55 / .35	SGPM	.63	.80 / .36	SGPM	.40	.62 / .12	SGPM	.70	.88 / .33	FL	.33	.57 / .03
14	SGIQ	.35	.46 / .23	SGIQ	.53	.74 / .22	TUT	.31	.55 / .02	TUT	.68	.87 / .30	TEXT	.29	.54 / -.01
13	TUT	.30	.41 / .18	OBJ	.36	.63 / .01	SGIQ	.31	.55 / .02	VID	.55	.81 / .10	STUD	.27	.53 / -.03
12	VID	.18	.30 / .05	TEXT	.32	.61 / -.04	EXP	.25	.51 / -.05	EXP	.37	.72 / -.13	TALC	.24	.50 / -.07
11	TALC	.13	.25 / .00	STUD	.28	.58 / -.08	EXAM	.20	.47 / -.10	SGIQ	.32	.69 / -.19	TUT	.18	.46 / -.13
10	TEXT	.10	.22 / -.03	TUT	.21	.52 / -.16	FL	.17	.44 / -.13	AUD	.28	.67 / -.23	VID	.17	.45 / -.14
9	FL	.05	.18 / -.08	TALC	.21	.52 / -.16	TALC	.05	.34 / -.25	TALC	.10	.55 / -.40	SGPM	.13	.41 / -.18
8	SD	-.01	.12 / -.14	VID	.21	.52 / -.16	VID	-.04	.26 / -.33	SD	.05	.52 / -.44	EXAM	.09	.38 / -.22
7	EXAM	-.02	.11 / -.15	SD	.15	.48 / -.21	PROBS	-.13	.17 / -.41	FL	.03	.50 / -.46	SGIQ	.02	.32 / -.28
6	STUD	-.03	.10 / -.16	EXAM	-.09	.27 / -.43	STUD	-.14	.16 / -.42	EXAM	-.04	.45 / -.51	AUD	-.07	.24 / -.36
5	AUD	-.13	-.00 / -.25	SAMPT	-.15	.21 / -.48	AUD	-.19	.11 / -.46	STUD	-.16	.35 / -.59	SAMPT	-.10	.21 / -.39
4	EXP	-.16	-.03 / -.28	FL	-.24	.12 / -.55	OBJ	-.22	.08 / -.48	SAMPT	-.24	.27 / -.65	SD	-.16	.15 / -.44
3	SAMPT	-.20	-.08 / -.32	PROBS	-.35	.00 / -.63	TEXT	-.27	.02 / -.52	TEXT	-.34	.17 / -.70	OBJ	-.39	-.10 / -.62
2	OBJ	-.33	-.21 / -.44	AUD	-.47	-.14 / -.71	SD	-.27	.02 / -.52	PROBS	-.41	.09 / -.74	PROBS	-.46	-.18 / -.67
1	PROBS	-.33	-.21 / -.44	EXP	-.63	-.36 / -.80	SAMPT	-.43	-.16 / -.64	OBJ	-.67	-.28 / -.87	EXP	-.53	-.27 / -.72

KEY ON NEXT PAGE

Table 7 (cont'd)

Key for Instructional Components

AUD	Audio Tapes
VID	Video Tapes
EXP	Experiments
SD	Self-Demonstrations
TUT	Exam Tutors
TEXT	Reading Textbook
PROBS	Practice Questions & Problems
TALC	Learning Center Tutors
STUD	Discussions with Other Students
OBJ	Reviewing Learning Objectives
FL	Film-Loops
SAMPT	Sample Tests
EXAM	Unit Exams
SGPM	Programmed Materials in Study Guide
SGIQ	Integrated Short-Answer Questions in Study Guide

in the study guide, exam tutoring, video-tapes, and learning center tutoring. Those which seem to have the lowest achievement value overall are audio tapes, experiments, sample tests, learning objectives, and practice problems. From this information, one might be tempted to encourage more use of those in the first group and de-emphasize those in the latter group. A closer inspection of the pretest groups in the table suggests that this would not be a very prudent course of action. As can be seen, very few of the components have uniformly positive or negative correlations over all four pretest groups. For example, learning objectives (OBJ) occupies ordinal position #2 overall and position #13 in the LP-LM group. If the information for this component is extracted from the table and plotted separately, the line in Figure 2 results. Apparently learning objectives have considerable achievement value for a particular group of students in spite of the overall negative correlation.

One interpretation of this effect is as follows: Since the LP-LM student is operating with a low level of subsumers, he finds it difficult to organize the material to be learned without some form of assistance. A list of learning objectives describes the breadth and depth of concepts to be covered in a particular unit of instruction, and indicates the criteria on which the achievement of the objectives will be judged. The objectives provide the low subsumer student with a preliminary overview of the concepts and allow him sumultaneously to evaluate his familiarity and degree of cognitive development in relation to them. During instruction, the objectives allow the student to focus on a single concept or skill until a fair degree of mastery is achieved. This is particularly important

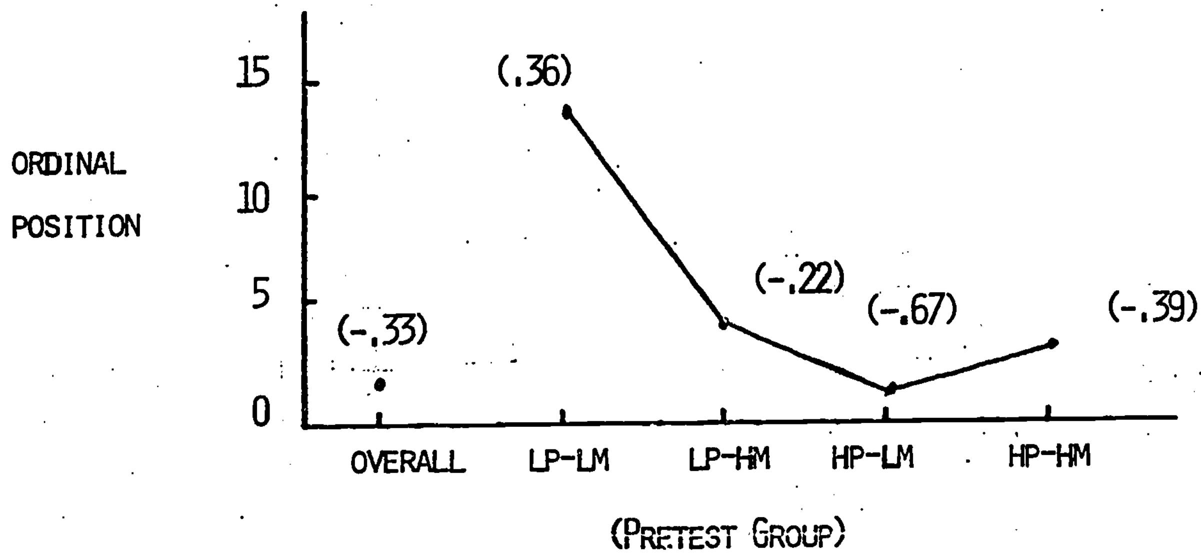


FIG. 2. ORDINAL POSITION OF CORRELATION BETWEEN FINAL GRADE AND PERCENT TIME DEVOTED TO LIST OF LEARNING OBJECTIVES (IN PARENTHESIS) BY PRETEST GROUPS.

when the concept or skill is to some degree prerequisite to subsequent learning. During the consolidation, review and self-testing phases of instruction, the objectives can provide a brief but concentrated outline of important concepts to which the student can refer.

One of the outcomes of this kind of analysis is that it allows one to make modality recommendations to future students based on the past performance of other students with similar characteristics. Whether these kinds of recommendations would prove worthwhile in terms of better providing for individual differences is not clear, but an experiment of this type would not be difficult to carry out.

3. Learning Efficiency

Students were asked to indicate the average amount of time they devoted per unit to each of the instructional components. The sum of these times was the average study time per unit. The inverse of this time was defined as a measure of learning efficiency. Another measure, termed "group efficiency," was defined and is discussed under "post-entry factors" in this section.

a. Entry Factors

Of the many factors which could be expected to bear some relationship to learning efficiency (essentially all items appearing on the Background Questionnaire plus the pretest scores), only a few were found to have a substantial correlation with learning efficiency. Surprisingly sex correlated rather high ($r = .42$) which indicates a slightly higher learning efficiency for males. Although it is difficult to find a convincing argument to explain this effect, the following is offered as a partial explanation: Since much of the learning which is rewarded in elementary and high schools is essentially rote, it is possible that females, maturing somewhat sooner than males, are conditioned to capitalize on a rote learning paradigm in the lower grades and cannot as easily adjust in college to situations requiring the meaningful acquisition of information. Further investigation of this effect is suggested.

Subsumers which had the strongest correlations with efficiency were those which had a clear and direct relationship to the subject matter under consideration, i.e., the student's possession of physics and mathematics concepts on entry to the course. See Table 8. Other more general factors such as having taken high school physics or not, grade in high school physics, grade aspirations, mathematics course background, and verbal scholastic aptitude showed a very low or nearly zero correlation with efficiency. This result is predicted by and lends support to a basic contention of Ausubelian learning theory that the most important factor influencing learning is the learner's possession of those concepts which have the closest content specific associations with the material to be learned.

b. Post-Entry Factors

No meaningful correlations were found to exist between post-entry variables and overall learning efficiency. Efficiency was therefore investigated on a unit-by-unit basis for groups of students with varying physics and mathematics aptitudes on entry to the course. A variable designated as "group efficiency" was calculated for each of the four pretest groups by dividing the percent of students passing each unit by the average amount of time taken to pass that unit. Thus a

TABLE 8

Correlation of Entry Variables with Learning Efficiency

$r \geq |.25|$

hysics Pretest (Understanding Subscale)

cale: Number correct out of 27.

= 56

= .42 sig. < .001

ysics Pretest (Application Subscale)

ale: Number correct out of 15.

= 56

= .37 sig. < .003

ysics Pretest (Total Score)

ale: Number correct out of 50.

= 57

= .39 sig. < .001

th Pretest (Manipulation Subscale)

ale: Number correct out of 16.

= 63

= .26 sig. < .020

8. Math Pretest (Interpretation Subscale)

Scale: Number correct out of 9.

n = 62

r = .28 sig. < .014

9. Math Pretest (Total Score)

Scale: Number correct out of 35.

n = 63

r = .31 sig. < .006

10. Physics Pretest Total and Math Pretest To

Scale: Number correct out of 85.

n = 57

r = .43 sig. < .001

group having a large fraction of students passing a given unit in a small amount of time would have a high group efficiency for that unit.

Students scoring high on the mathematics pretest showed the greatest overall persistence in passing units as is shown in Figure 3. This was probably due to a lower likelihood of these students encountering serious delays in their progression - mathematical skills were assumed and not taught per se in the course.

The possession of mathematical skills on entry to the course had a strong influence on the number of days necessary to complete each of the first few units but this relationship disappeared thereafter. Apparently those students who were initially deficient in mathematics were able to acquire the necessary mathematical skills via the physics presented in the earlier units.

Mathematics subsumers were found to be significant factors in predicting overall group efficiency. It seems reasonable that a student's ability to process physical concepts would be related to his possession of related mathematical skills since much of physics is involved with mathematical derivations from fundamental concepts.

Physics subsumers were not good predictors of overall group efficiency but an interesting pattern was uncovered. See Figure 4. Students low in both physics and mathematics subsumers showed less efficiency in low level units occuring at the beginning of a hierarchical sequence and greater efficiency in high level units occuring near the end of a hierarchical sequence than students low in mathematics but high in physics subsumers. It was reasoned that this result was probably due to the effects of (1) a negative learning set on the part of the high physics

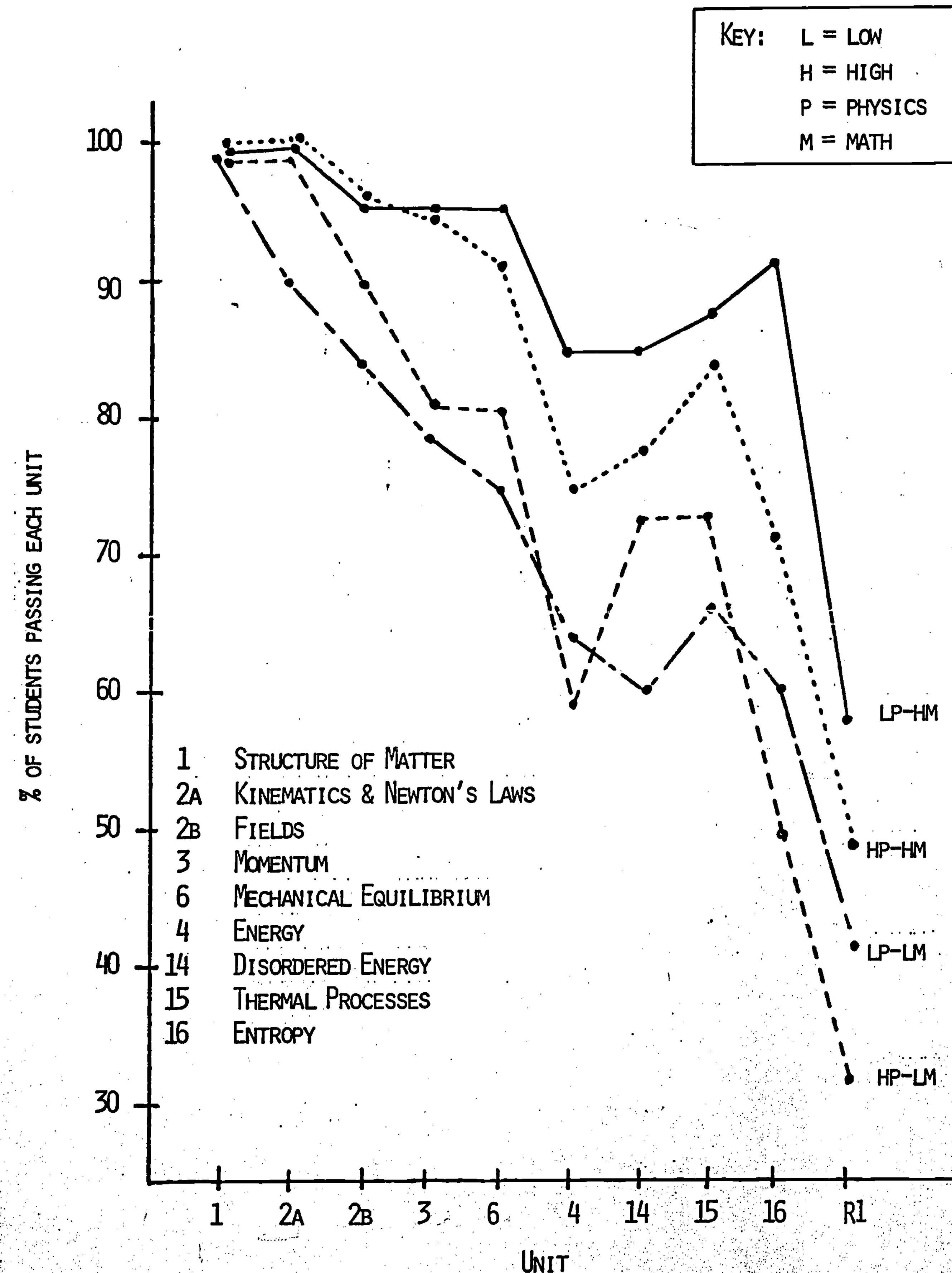


FIG. 3. PERCENT OF STUDENTS PASSING EACH UNIT FOR 4 PRETEST GROUPS

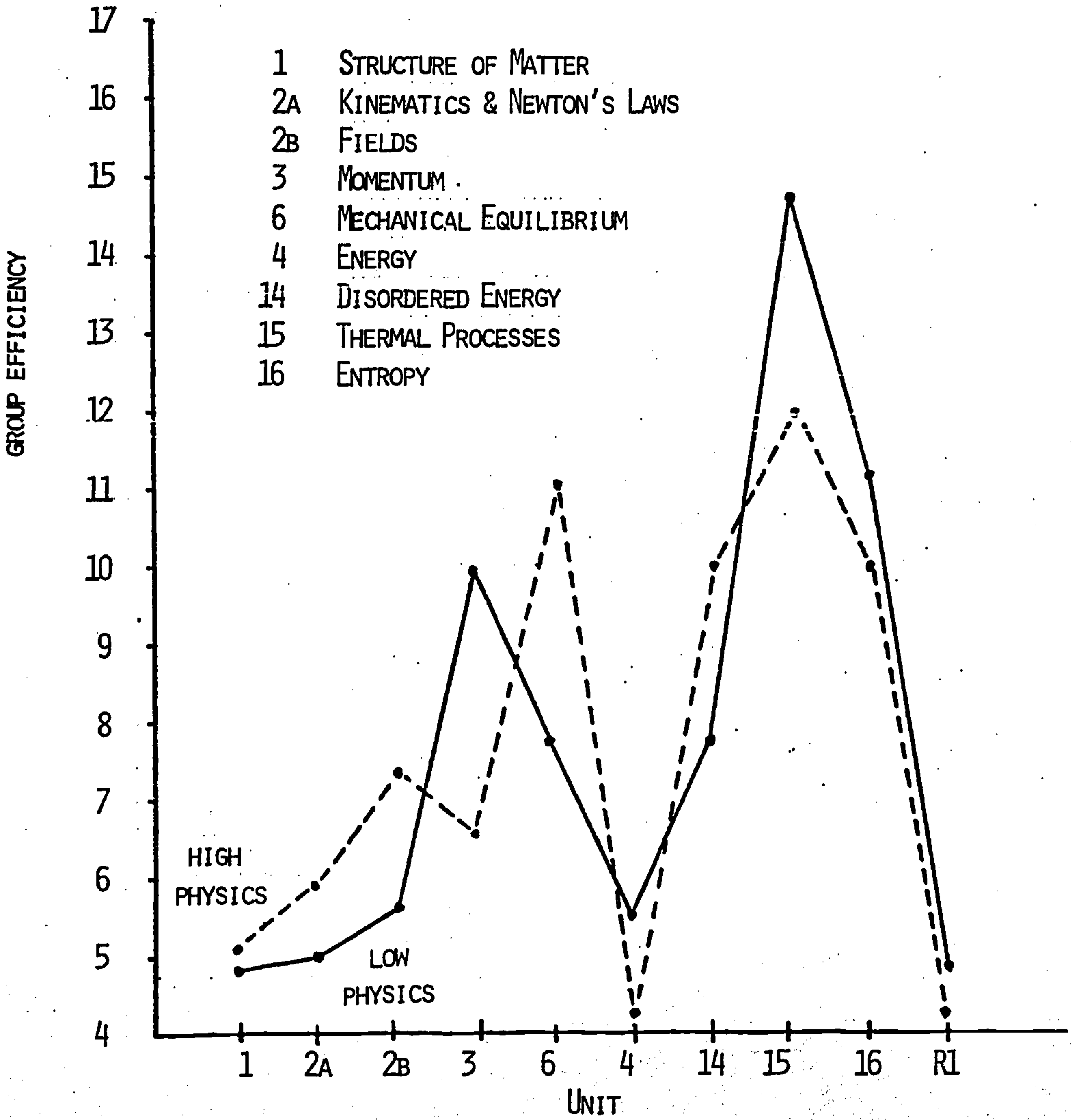


FIG. 4. GROUP EFFICIENCY ON EACH UNIT FOR TWO PRETEST GROUPS: LOW MATH-LOW PHYSI VS. LOW MATH-HIGH PHYSICS.

group resulting from an underestimate of the depth of understanding which would be required on each unit, (2) the low physics group taking advantage of a rare opportunity for them to achieve a high grade in a typically difficult science course, and (3) the relatively high percentage of grade conscious pre-veterinary, pre-medical, and pre-dental students in the low physics-low mathematics group.

It was also found that all four subsumer groups showed an overall trend towards increased learning efficiency as the semester progressed. This also agrees with Ausubel's hypothesis that meaningful learning should lead to increased learning efficiency since the accumulation of subsuming concepts should serve to facilitate subsequent acquisition.

G. Summary

There are sound psychological, humanistic, affective, and cognitive reasons for continuing with the self-paced format. The results indicate that students are deriving greater cognitive and affective benefit from the present format than they were from the traditional lecture-recitation-lab format. Since the content, objectives, and evaluation procedures have significantly changed since the course was taught traditionally, it is virtually impossible to definitively compare overall achievement under the two formats. Efforts at comparing overall achievement under general course format "A" to the overall achievement under general course format "B" have invariably resulted in either "no significant differences" or the inability to clearly ascertain causal explanations for small, albeit "statistically significant," differences. If superior overall achievement under format "A" was due to greater study time, a disregard for affective goals, a de-emphasis on the development of laboratory skills, etc. it would not answer the question of which format was superior, and yet this is so often done without due consideration to these other variables. Our philosophy has been to begin with the notion that each student is an individual, possessing a unique set of characteristics, differing in goals, aspirations, interests, intellectual skills, backgrounds, learning styles, motivations, learning rates, etc. The instructional procedures reflect this recognition of the uniqueness of human beings and our efforts have been directed toward providing forms of instruction which we feel can better match the diverse characteristics of our student population.

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