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AUTHOR Pascarella, Ernest T.
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ABSTRACT

Multiple regression analysis was employed to determine the interactive effects of student motivation, prior mathematics preparation, and instructional method on achievement in a calculus course taught in lecture and Personalized System of Instruction (PSI) formats. A significant interaction between mathematics preparation and instructional method was found at $p < .01$. A plot of the mathematics preparation by achievement regression lines for each instructional method indicated that the effects of PSI in improving achievement were most pronounced for students at the relatively lowest levels of prior mathematics preparation and tended to diminish progressively as level of mathematics preparation increased. (Author/DT)

APTITUDE-TREATMENT INTERACTION IN A COLLEGE CALCULUS COURSE TAUGHT IN PERSONALIZED SYSTEM OF INSTRUCTION AND CONVENTIONAL FORMATS

Ernest T. Pascarella
Associate Director for Research
Center for Instructional Development
Syracuse University
Syracuse, New York 13210

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ABSTRACT

A quasi-experimental design was employed to investigate the interactive effects of prior mathematics preparation and instructional method on post-course achievement in a college calculus sequence taught in personalized system of instruction (PSI) and conventional, lecture/problem-solving formats. A test for the homogeneity of regression coefficients indicated a significant ($p < .01$) prior mathematics preparation x instructional method interaction. This suggests that the effects of the PSI instructional method in improving achievement were not constant for all levels of prior mathematics preparation. The most dramatic differences in post-course achievement favoring the PSI method accrued to those students at the relatively lowest levels of prior mathematics preparation. Moreover, as level of prior mathematics preparation increased, the achievement differences between instructional methods tended to decrease.

Based on the availability of an extensive body of research evidence, there appears to be little doubt about the effectiveness of the personalized system of instruction (PSI) or the "Keller Plan" (Keller, 1968) in improving both students' attitudes toward a course and their performance on a variety of course achievement measures. The basic features of PSI courses include the following: (a) individual student pacing; (b) mastery of material prior to proceeding to the next unit; (c) utilization of student tutors; (d) use of study guides to impart critical information; and (e) lectures for motivation and stimulation rather than to impart information (Kulik, Kulik and Carmichael, 1974). Various modifications of these basic characteristics have been made in implementing PSI in diverse content areas.

Born and Davis (1974); Born, Gledhill and Davis (1972); Cooper and Grenier (1971); Green (1971); Riner (1972); Roth (1973); Shepard and MacDermot (1970) and Witters and Kent (1972) are all representative studies or reports which indicate that, when compared to conventional lecture approaches, the general PSI model produces significantly more positive student attitudes toward a course and/or significantly higher achievement. The results of these studies are from a variety of disciplines including psychology, physics, mathematics and engineering. A comprehensive review of PSI in science teaching is provided by Kulik, Kulik and Carmichael (1974).

One potential problem with the studies cited above, and indeed with most PSI investigations, is that they treat comparative student performance in PSI and conventional courses globally. As a result, they may mask the presence of interactions between distinctive instructional treatments on the one hand, and different learner traits and/or aptitudes on the other. It may be that the effects of PSI, or any individualized instructional system for that matter, are not homogeneous across the full range of aptitudes or personality orientations which the student brings to the course. Thus, PSI may be most effective for a subgroup of students at certain levels of a particular trait while conventional methods may be more appropriate with another subgroup of students at different levels of the same trait. For still another subgroup, achievement may be unaffected by instructional treatment.

Unfortunately, it is only recently that researchers have attempted to disaggregate the global effects of PSI (Fernald, Chiseri, Lawson, Scroggs and Riddell, 1975) or to relate performance in PSI courses to learner traits and/or abilities (e.g., Johnson and Croft, 1975; Born, Gledhill and Davis, 1972; Morris and Kimbrell, 1972; Austin and Gilbert, 1973; Kulik, Kulik and Milholland, 1974). The results of this research are not particularly conclusive. Some studies suggest that lower ability students benefit most, in terms of achievement, from PSI; others indicate that the greater benefits accrue to higher ability students, and still others suggest that students in PSI courses improve a constant amount in achievement regardless of ability level. These conflicting findings may stem in part from heterogeneous experimental conditions and the failure to employ a standard design for the analysis of the interaction between learner traits and instructional methods.

Despite their equivocal nature, however, the findings of these studies would appear to indicate that prior student aptitudes and preparation may be differentially related to achievement in PSI and more conventional instructional formats. The purpose of the present investigation was to examine the interactive effects of prior mathematics preparation and instructional method on achievement in an introductory calculus course taught by both PSI and conventional approaches.

METHOD

Course and Treatments

The focus of the study was the first semester of a four-semester introductory calculus sequence (Mathematics 295) intended for potential science and mathematics majors. The course typically enrolls over 300 students in the first semester. A number of sections were offered to students in a modified PSI format (entitled Self-Paced Calculus) which allowed for self-pacing, optional attendance at lecture/problem solving sessions, scheduled tutorials for individual help and testing, and complete mastery of a unit of material before preceeding to subsequent units. Unit mastery was demonstrated by means of a unit test which the student could take whenever he or she felt sufficiently prepared. Students failing the unit test were allowed to take alternative test forms covering the same material until they mastered it. Additionally, students could complete bonus problems or retake an alternate form of a unit test which they had passed to improve their grade.

In order to alleviate procrastination, which appears to be a pervasive problem in many PSI courses, students were informed of a suggested schedule for completing unit tests. The minimum number of tests they could complete during the semester was eight, while a maximum was not set. (In order to complete the four-course sequence a student had to pass 42 unit tests. A continuous registration and flexible credit procedure permitted students to complete almost any number of unit tests--and thus earn additional academic credits during any one semester--with no additional tuition cost.)

Tutorials were scheduled for four hours each weekday afternoon. Students could use the tutorial sessions for individual help and study or for completing unit tests. All unit tests were taken and graded during the tutorials. In addition, a detailed study guide was prepared for each unit. The study guide listed the specific topics to be learned, gave references and expanded on points made in the course text, provided exercises for practice and a sample unit test, and described bonus problems which students could complete for additional points. Students received a "Self-Paced Calculus Student Handbook" at the beginning of the course which completely described course procedures. Included were sections on course requirements, credit hours and pacing, instructional facilities and materials, tutorial periods, examination procedure, and grading.

The conventional method of instruction consisted of three hours of lecture/ problem solving sessions per week. Approximately 24 students were assigned to each class section. The classes were taught by both full-time faculty and graduate teaching assistants. Both the conventional and self-paced methods covered essentially the same content and both methods used the same primary textbook: Analytic Geometry and the Calculus, 3rd Edition by A. U. Goodman.

Subjects

The subjects in the study were 248 students, 60 from the self-paced method and 188 from the conventional method. Since all students who took the final examination from the self-paced method earned a semester grade of C or above (the rest being "drops" or F's), students receiving a D or F in the conventional sections were eliminated from the analysis. The proportion of drops or F grades for the self-paced method was 28.6%. This compared to 22.1% of the conventional subjects receiving a grade of D, F or incomplete. A test for the significance of the difference between these two percentages was non-significant ($p > .20$).

Variables

In order to study the interaction between student traits and instructional methods without confounding the effects of the method, one needs to measure student traits prior to, or at the very beginning of, the course of instruction. Prior to beginning Math 295 each student in the study had completed the Mathematics Placement Examination (MPE) (Myerberg and Kelly, 1972). The MPE is a 33 item test which has been validated on a sample of 1422 students in eleven undergraduate mathematics courses at Syracuse University. It was found to correlate .48 with-first semester grades in Math 295. This compared with a correlation of .45 between first semester Math 295 grades and the Mathematics score of the Scholastic Aptitude Test. The MPE was used in place of the MSAT because scores on the latter measure were not available for all subjects in the study.

While the MPE ostensibly measures a student's prior level of achievement in mathematics skills, its correlation of .59 with the MSAT suggests that it is quite probably also a measure of mathematics aptitude. For this reason it will be regarded in the present study as a measure of prior mathematics preparation, defining this construct as encompassing both aptitude and achievement. The computed Kuder-Richardson 20 (internal consistency) reliability coefficient for the MPE is .84. Since an important emphasis of PSI is on mastery learning at one's own pace, it was hypothesized that prior mathematics preparation (as measured by the MPE) would have a significantly stronger association with course achievement in the conventional method than in the PSI method. Thus it was also expected that the largest differences in achievement favoring the PSI method would be observed at the relatively lowest levels of prior mathematics preparation.

The dependent variable (course achievement) was an eight-item, 132-point, common end-of-semester examination which covered the equivalent in content of the first eight units of material in the self-paced method. The test was constructed jointly by faculty members in both methods and scored by six independent judges who had no association with either the self-paced or conventional sections. Each judge scored only one part of the test for each student, and was unaware of which instructional method any particular student was in. The split-half reliability of the examination, adjusted by the Spearman-Brown formula, was .72.

Design and Statistical Analysis

Because the self-paced alternative presented students with a dramatically different learning format from conventional methods, faculty were opposed to students' being assigned to it on the basis of chance. This prevented the random assignment of subjects to treatments and led to the adoption of a quasi-experimental approach. The quasi-experimental design employed was a pre-post, non-equivalent control group design (Campbell and Stanley, 1963) in which the subjects could elect to take either instructional option. Since the primary threat to internal validity in this design stems from various forms of self-selection bias, the design is considerably strengthened if equivalence can be demonstrated on pre-treatment variables which may have substantial correlations with subsequent performance on the dependent variable (Campbell and Stanley, 1963).

Differences between the conventional and self-paced students in the means and variances of the MPE were both non-significant. The F ratio for the difference between MPE means was 1.15 with 1 and 246 degrees of freedom ($p > .30$), while the ratio of the group variances fell within the upper and lower rejection regions of the F distribution at $p > .25$ (Hays, 1973).

Additionally, pre-enrollment scores on the Activities Index - AI (Stern, 1970), a 12-dimension measure of personality needs, had been completed by 132 students from the conventional method and 47 students from the self-paced method. The AI is a widely used personality inventory consisting of the following subscales: Self-Assertion, Audacity-Timidity, Intellectual Interests, Motivation, Applied Interests, Orderliness, Submissiveness, Closeness, Friendliness, Expressiveness-Constraint, Egoism-Diffidence and Sensuousness. A multivariate analysis of variance yielded non-significant differences between the self-paced and conventional groups along all twelve personality need scales of the AI. The multivariate test was non-significant for both males and females. The multivariate F-ratio for males was 0.36 with 12 and 124 degrees of freedom ($p > .60$) while the multivariate F-ratio for females was 0.91 with 12 and 29 degrees of freedom ($p > .60$). Moreover, none of the univariate F-ratios for either males or females were significant at $p < .20$). Thus, even though strict experimental controls were not possible in the study, the self-paced and conventional groups nevertheless appear to be quite similar in terms of both prior mathematics preparation and a range of personality dimensions, including personal motivation.

Demonstrating such pre-treatment equivalence between groups in quasi-experimental designs does not permit the same kinds of causal inferences as do true experiments in which subjects can be randomly assigned to treatments. Clearly self-selection could have created pre-treatment bias in unmeasured variables which may affect achievement--an unequivocal limitation of the present study. However, self-selection did not appear to create pre-treatment bias across a wide range of learner characteristics, including levels of prior mathematics preparation and personal motivation.

Multiple regression analysis with semester examination scores as the predicted variable was the mode of statistical analysis employed. The predictor variables were instructional method, Mathematics Placement Exam scores (treated as a covariate), and an interaction vector created by multiplying each student's instructional method by his or her MPE score. Instructional method was effect-coded according to Kerlinger and Pedhazur (1973). Students in the self-paced method were coded 1 and students in the conventional method were coded -1. In computing the multiple regression the effects of instructional method were computed while controlling for MPE scores, the effects of the MPE were computed while controlling for instructional method, and the effects of the MPE x instructional method interaction were computed while controlling for both instructional method and MPE scores. The critical level of significance for all statistical tests was set at the .01 level.

The test for the significance of the MPE x instructional method interaction is in actuality a test for the homogeneity of regression coefficients between treatments. A significant interaction would indicate that the slopes of the least squares regression lines, representing the respective MPE - achievement relationships for each instructional method, are not parallel. Separate regression lines would therefore be required to most accurately represent the data.

RESULTS

A preliminary analysis was conducted for each instructional method to determine if the relationship between MPE scores and semester examination scores was linear or curvilinear. In both instructional methods the test for deviation from linearity (Kerlinger and Pedhazur, 1973) was non-significant ($p > .10$). This suggests that a linear relationship best characterized the association between prior mathematics preparation and examination achievement.

Table 1 shows the results of the multiple regression analysis of semester examination scores. The total variance accounted for was 26.75% (multiple $R = .517$, $F = 29.70$ with 3 and 244 degrees of freedom, $p < .001$). As the Table indicates, the effects due to level of prior mathematics preparation and instructional method were both statistically significant. The mean semester examination score, adjusted for prior mathematics preparation, was 98.89 ~~99.71~~ for the self-paced method, as compared to 82.53 for the conventional method.

It must be pointed out that the above finding may be misleading and must be interpreted with considerable caution. As suggested by Games (1976), the most appropriate use of covariance control to adjust treatment effects obtains when it is possible to randomly assign subjects to treatments. This was not possible in the present study. However, it should be stressed that the primary focus of the study was not to demonstrate main-effects achievement differences between PSI and conventional methods. This has been well documented by prior research. Rather, the primary aim of the study was to determine if the effects of PSI on achievement are the same for students at different levels of prior mathematics preparation.

A second reason why the finding of a significant instructional method main-effect may be misleading is the presence, as shown in Table 1, of a significant prior mathematics preparation x instructional method interaction. This inter-

TABLE 1

SUMMARY OF MULTIPLE REGRESSION ANALYSIS (N=248)

VARIABLE	PROPORTION OF VARIANCE[a]	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F
MATHEMATICS PLACEMENT EXAMINATION - MPE (A)	.1317	16053.04	1	16053.04	43.97**
INSTRUCTIONAL METHOD ADJUSTED FOR MPE SCORES (B)	.0971	11808.72	1	11808.72	32.34**
A x B	.0217	2637.81	1	2637.81	7.23*
RESIDUAL	.7325	89079.80	244	365.08	

* $p < .01$

** $p < .001$

[a] Proportions of variance do not sum to 1.00 because of adjustments for correlations among variables.

action indicates that a common regression coefficient, one of the assumptions of covariance adjustment, is not adequate for describing the MPE - achievement relationship across the two instructional methods. More substantively, this interaction, though modest in terms of variance explained, suggests that the possible effects of the self-paced (PSI) method in improving achievement over the conventional method are not constant for all levels of prior mathematics preparation.

Figure 1 plots the separate least squares regression lines representing the MPE x instructional method interaction. The regression equations for the two methods are as follows (where X is the score on the MPE and Y is the score on the semester examination):

$$\text{Conventional:} \quad Y = 2.609X + 43.276$$

$$\text{Self-Paced (PSI):} \quad Y = 0.725X + 88.424$$

The two regression lines intersected at an MPE score of 24.03. (This can be rounded to an MPE score of 24 since the MPE can take only whole number integers between 1 and 33.) Subjects' scores on the MPE in the present study ranged from 5 - 26.

As further shown in Figure 1, the relationship between prior mathematics preparation and examination achievement is considerably stronger for the conventional than for the PSI method. For every increase of one point on the MPE there is an average increase of approximately 2.61 examination score points in the conventional method as compared to an average increase of 0.73 examination points in the PSI method. An additional indication of this tendency is shown by the respective correlations between the MPE and examination achievement for the two instructional methods. The correlation in the conventional method was .434 as compared to .217 in the PSI.

An additional analysis was conducted with a technique developed by Johnson and Neyman (1936) which permits the determination of the range of MPE scores for which it is reasonable to assume that achievement differences between the two methods are statistically significant. The basic statistics necessary to conduct the Johnson-Neyman analysis are shown in Table 2. The results of the analysis indicated that the range of MPE scores for which statisitically significant ($p < .01$) differences in achievement scores existed between the two instructional methods was from 5 to 18.84 (since the MPE can take only whole number scores this range included actual scores from 5 to 18). Approximately 81.9% of the total distribution of subjects' MPE scores fell within this region of statistically significant differences. A region of non-significant differences extended from an MPE score of 18.85 to a score of 29.22 (rounded to actual whole number scores of 19 - 29). Since the total range of MPE scores in the study was

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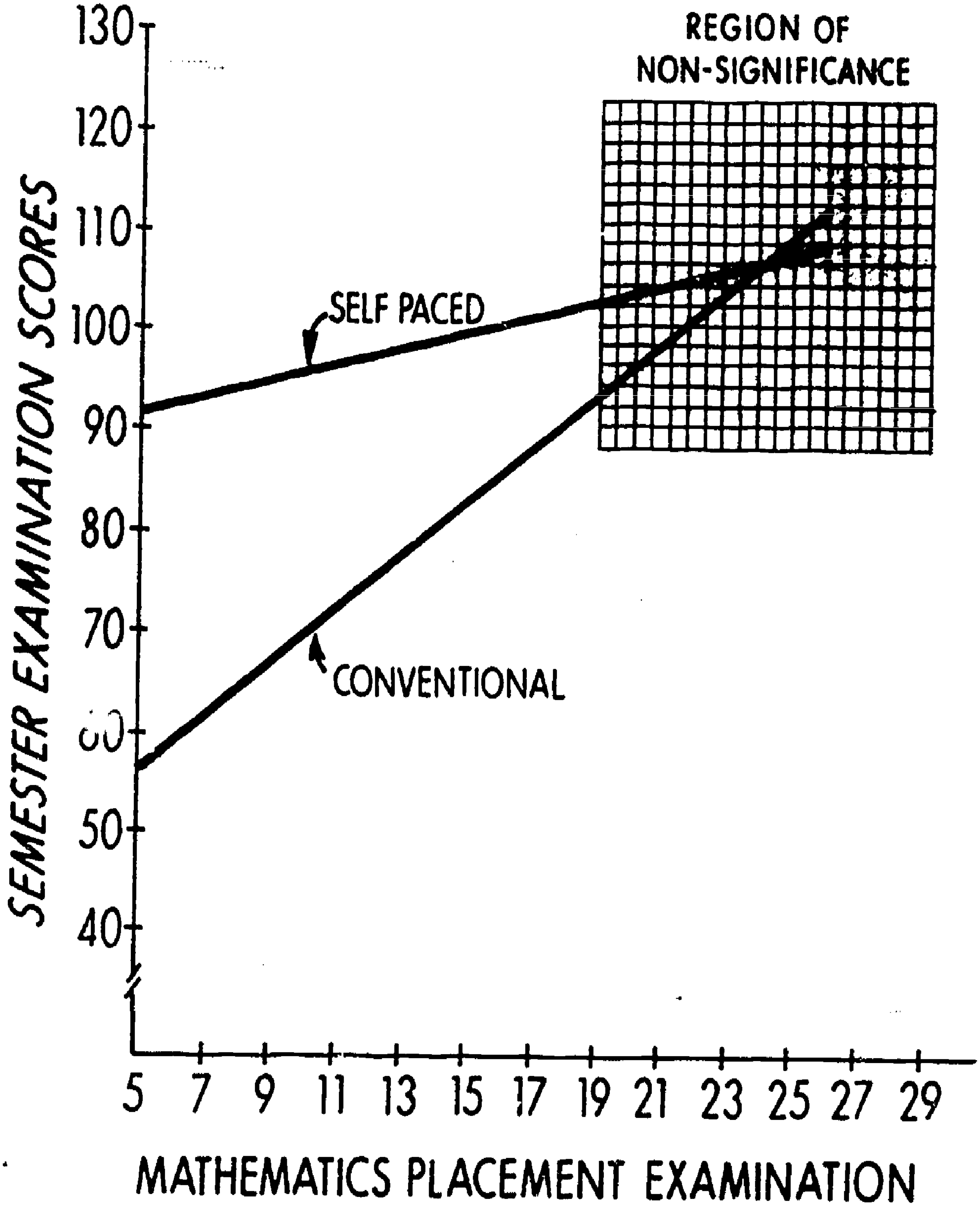

Figure 1: MATHEMATICS PREPARATION X INSTRUCTIONAL METHOD INTERACTION

TABLE 2

BASIC STATISTICS FOR JOHNSON-NEYMAN ANALYSIS

	SELF-PACED (N=60)	CONVENTIONAL (N=188)
MATHEMATICS PLACEMENT EXAM		
mean	15.58	14.95
s.d.	4.17	3.76
SEMESTER EXAMINATION SCORES		
mean (unadjusted)	99.72	82.28
s.d.	13.90	22.65
INTERCEPT	88.42	43.28
SLOPE	0.73	2.61
ERROR SUM OF SQUARES	89079.8	

1.1

from 5 - 26, the second region of significance fell outside the research range of interest.

SUMMARY AND CONCLUSIONS

The findings of the study suggest that the effects of the Personalized System of Instruction in improving achievement over a more conventional format are not homogeneous across all levels of prior mathematics preparation. As hypothesized, the most dramatic improvements in achievement accrued to those PSI students at the relatively lowest levels of mathematics preparation--suggesting perhaps that PSI may be most effective for students who are the least well prepared in a particular content area. As level of prior mathematics preparation increased, the magnitude of the mean achievement differences between the two instructional methods tended to decrease. Significantly ($p < .01$) higher mean semester achievement scores were indicated for PSI subjects whose MPE scores fell within the range from 5 - 18. However, for those students whose level of prior mathematics preparation placed them approximately in the top 20% of the distribution (MPE scores from 19 - 26), the mean achievement score difference between instructional treatments was not statistically significant. Thus, the findings of the study do not suggest that students at the relatively highest levels of prior mathematics preparation achieve at significantly different levels in either instructional method.

The results of the study also suggest that level of prior mathematics preparation has a somewhat stronger association with course examination achievement in the conventional method than in the PSI method. Such a finding is perhaps not particularly surprising. One might reasonably expect that such instructional features as required unit mastery and the provisions for self-pacing and continual practice of the criterion behavior would function to attenuate the relationship between individual student differences in prior mathematics preparation and subsequent course achievement.

One possible alternative explanation for the MPE x instructional method interaction found in the study is the presence of a ceiling effect. That is, since so many of the PSI subjects score 100% (132 points) on the achievement measure, the MPE - achievement regression line is depressed more than it would have been had a more difficult measure of achievement been given. This, however, would not appear to be the case in the present study since only one of the PSI subjects scored above 125 on the dependent variable (129) and none of the 248 subjects scored 100% on the examination.

Despite the suggested equivalence of the treatment groups on prior mathematics preparation, motivation level and eleven other personality dimensions, the need to employ a quasi-experimental design in the study requires considerable caution in interpreting the findings. This is particularly true in terms of causal inferences. Particular caution should also be observed in generalizing the findings to content areas other than calculus. Clearly, further research is needed on additional samples, not only to cross-validate the present findings experimentally, but also to delineate more clearly the effects of PSI on different kinds of learners. The results of this investigation, while not conclusive in themselves, nevertheless suggest that trait-treatment interaction may provide a fruitful approach to this inquiry.

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