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AUTHOR	Resnick, Lauren B.; Wang, Margaret C.
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ABSTRACT

This paper examined the performance of kindergarten and first grade children in an inner-city school during the first full year of the Primary Education Project (PEP) Quantification (early mathematics) curriculum. The curriculum was based on a hierarchically sequenced set of objectives and accompanying criterion-referenced placement and diagnostic tests. Children were permitted to proceed through the curriculum at varied rates and in various styles. Two basic findings were reported and discussed: (1) strong performance on both the PEP curriculum and a standardized mathematics achievement test suggested the potential of an individualized, mastery curriculum for breaking the cycle of "cumulative deficit" in school performance; and (2) a decrease in predictive power of IQ test scores suggested that instruction in a hierarchically organized curriculum reduces dependence on generalized abilities, in favor of explicitly instructable ones. (ED)

IMPROVEMENT OF ACADEMIC PERFORMANCE OF POOR-PROGNOSIS CHILDREN THROUGH THE USE OF AN INDIVIDUALIZED INSTRUCTIONAL PROGRAM

Lauren B. Resnick and Margaret C. Wang

Learning Research and Development Center

University of Pittsburgh

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Abstract

Kindergarten and first grade children's performance during the first full year of use of the PEP Quantification (early mathematics) curriculum is examined for a predominantly poor and minority school. Two basic findings are reported and discussed: (1) strong performance on both the PEP curriculum and a standardized mathematics achievement test that suggests the potential of an individualized, mastery curriculum for breaking the cycle of "cumulative deficit" in school performance; (2) a decrease in predictive power of IQ test scores that suggests that instruction in a hierarchically organized curriculum reduces dependence on generalized abilities, in favor of explicitly instructable ones.

This paper will be of interest to educational researchers and curriculum designers, particularly those concerned with problems of education for poor and minority children.

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It has been widely observed that children who begin school at a relative disadvantage tend to fall increasingly further behind their more advantaged peers as they progress through the school grades. A possible reason for this phenomenon of "cumulative deficit" lies in the failure of certain children to have mastered critical prerequisites for early school performance. As a result, these children fail to master the material of the first year's curriculum; and since this material is in turn prerequisite to the next year's learning, they continue to move from grade to grade at a disadvantage. As unmastered prerequisites cumulate through successive years of school, the negative prognosis for school success increases.

If this analysis is correct, then a strategy for breaking the cumulative deficit cycle would need to: (1) begin very early to establish the prerequisites of school performance; and (2) assure that each child masters each succeeding set of objectives before proceeding to higher levels of instruction. This paper reports on the first year of experience with an early mathematics program designed to fulfill these objectives. The curriculum in question was developed as part of the Primary Education Project (PEP), one of the school development projects of the Learning Research and Development Center at the University of

Pittsburgh. The curriculum content and sequence of objectives were based on an intensive analysis of a set of mathematical behaviors which, taken together, reflect a stable number concept and provide a set of skills on which learning of more advanced mathematical material can effectively be based. Objectives were organized into hierarchies which, according to both task analyses and empirical data, reflect the natural order in which children acquire the skills and concepts involved. An explanation of the methodology of curriculum analysis and detailed discussion of the introductory units of the curriculum appear in a monograph by Resnick, Wang, & Kaplan (1973). Empirical validations of some of the curriculum sequences are reported in two other papers (Wang, Resnick, & Boozer, 1971; Wang, 1973).

The PEP math curriculum was designed as a "mastery curriculum" (cf. Bloom, 1971; Glaser, 1968); that is, a curriculum in which provision is made to assure that every child learns every important objective regardless of the particular method used or the amount of time necessary for mastery. In practice, implementation of a mastery curriculum implies that children will be permitted to proceed through the curriculum at varied rates and in various styles. Thus, it is possible that some children will skip formal instruction in skills or concepts that they are able to master in other ways. This demand for individualization, in turn, requires that there be some method of assessing mastery of the various objectives in the curriculum. If children are to work only on objectives in which they need instruction and for which they are "ready," in the sense of having mastered major prerequisites, then teachers need to feel considerable assurance that mastery has in fact occurred.

In PEP classrooms, the need for assessment was met through frequent testing and systematic record keeping. A brief test for each objective in the curriculum was written (Wang, 1969). These tests directly sampled the behavior described in the objective. If the objective was counting objects, for example, the child was given sets of objects to count. The tests informed the teacher of the presence or absence of the behavior in question. Thus, the test items were a direct reflection of the curriculum objectives and defined very explicitly what the child was expected to learn.

After a child was socially comfortable in the classroom and routines were well established, the teacher or aide took him aside and began the testing program. The first task was to find his "entering level." This was normally done by administering a special "placement test," composed of a sampling of items from the units. Children were rated as mastering or not mastering each unit on the basis of this test. For units not mastered, tests on the individual objectives were then administered to determine on exactly which objectives the child needed to work.

When a child did not pass a test, indicating that he needed work on a given objective, he was given one or several "prescriptions," i.e., assignments of activities relevant to learning that objective. Prescriptions in the mathematics curriculum were extremely varied. For independent work by children, prescriptions ranged from interactive games for two or more children to formal written worksheets. Small group and individual "tutorials" with the teacher were also prescribed when needed. Conceptual mathematics teaching materials such as those developed by Montessori, Dienes, and Cuisenaire were used, along with materials from a number of different educational suppliers. Audio-visual devices such as the Language Master and Audio

Flashcard machines were used; and each teacher also developed many materials to meet specific needs.

By using the testing program the teacher was able to constantly check her success in teaching specific concepts. When a child had completed prescribed work on an objective, he was retested; if the objective was not mastered, further instruction was provided until mastery was demonstrated. It was possible for a child to work on several different objectives during a given instruction period, working up independent branches of the curriculum sequence. As the child progressed through the curriculum, a pretest on each new objective assured that he would be allowed to skip over objectives he had been able to learn on his own.

The PEP mathematics curriculum, as used during the period reported here, consisted of 14 units: the first eight units included 55 separate objectives designed to develop an operational number concept for sets up to ten, while the ninth through fourteenth units included 49 objectives designed to introduce higher numbers together with principles of grouping and place value fundamental to the decimal number system. Figure 1 shows the hierarchical sequence of units, their general content, and (in parentheses) the number of specific objectives in each unit.

The present study examines the degree to which a mastery curriculum such as the PEP math curriculum, based on a hierarchically sequenced set of objectives and accompanying criterion-referenced placement and diagnostic tests, can effect important changes in the early mathematics learning of children whose academic performance would normally be expected to be below grade level, and who thus would be likely to show cumulative deficits in learning in succeeding years. In addition, the study examines IQ as a predictor for performance in an

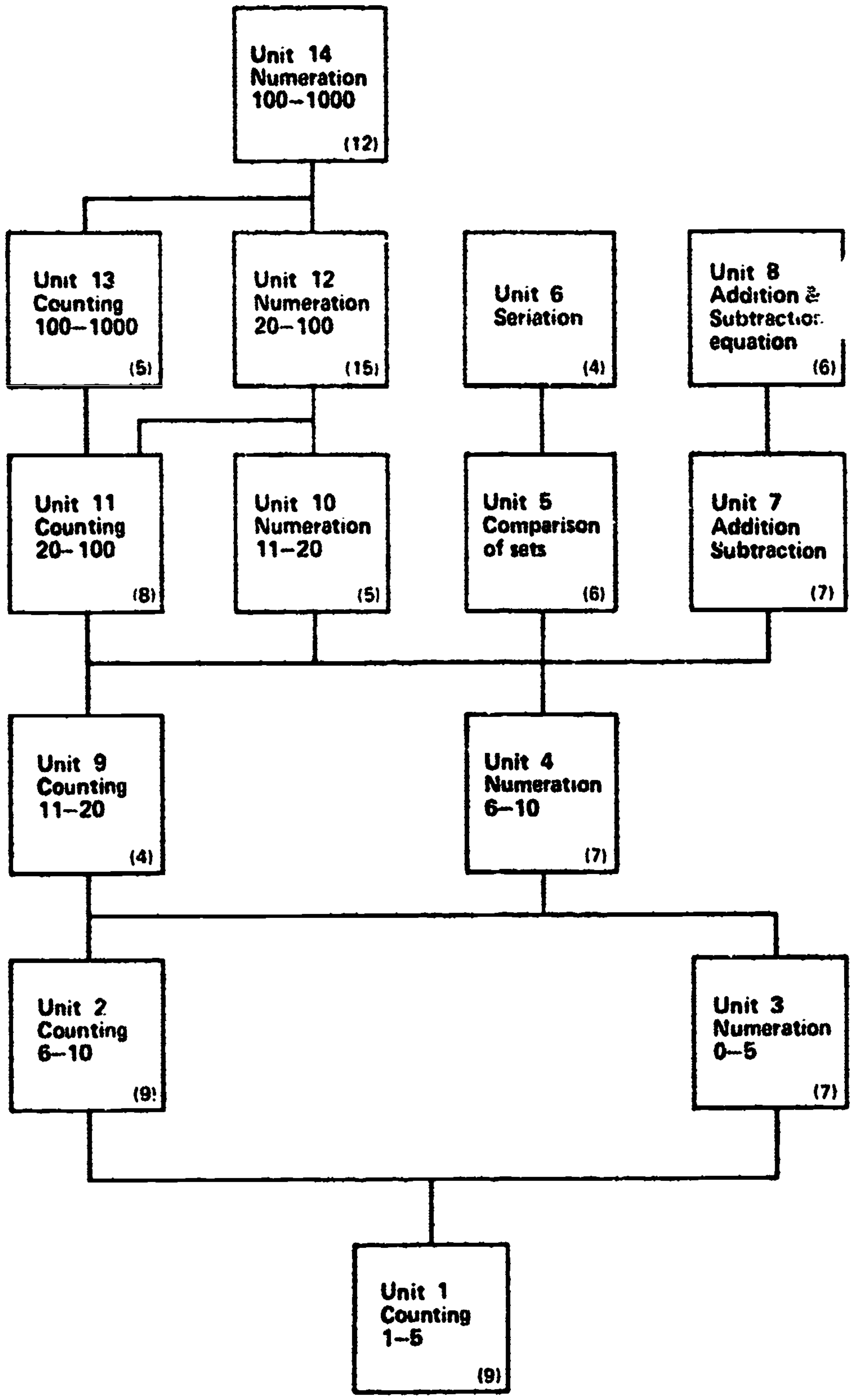

Figure 1. Sequence of PEP Mathematics Units.
Numbers in parentheses show number of objectives in unit.

individualized mastery curriculum, and the relationship between progress through the mastery curriculum and performance on a standardized achievement test. The study treats children's rate of progress through the PEP mathematics curriculum as both a dependent and an independent variable. Looking at student learning progress as a dependent variable, end-of-year position in the curriculum is examined as a function of IQ, past experience in the PEP program, and the child's level of prior learning, as measured by his position on the entering placement tests. Treating curriculum performance as an independent variable, the study examines the extent to which entry and terminal position in the PEP curriculum predict performance on standardized achievement tests. Standardized test scores are also examined with reference to IQ, and comparisons with a group not exposed to the PEP program are made.

Method

Subjects. The investigation was carried out in a public elementary school located in an inner-city neighborhood in Pittsburgh, Pennsylvania. The school is one of two developmental schools where the Learning Research and Development Center's programs are implemented and tested. The majority of students were from economically disadvantaged families, a large proportion of them living in public housing projects within walking distance of the school. However, a small percentage (4 to 7 percent) of the students were children of university faculty, staff, and graduate students, and other professional people. Eighty-five percent of the kindergarten and 90 percent of the first grade children were Black. Twenty-two percent of the kindergarteners and 38 percent of the first graders came from homes in which the father was not regularly present.

The performance of all kindergarten and all first grade children was studied over a one year period. Thirty-seven percent of the kindergarteners had participated in the PEP preschool program during the previous year. Seventy-eight percent of the first grade students had attended PEP kindergarten classes during the previous school year. In neither case, however, had the particular program under study here been in use the previous year.

Procedure. Student learning outcome measures for the present study were based on the test results obtained from the PEP criterion-referenced tests as well as the standardized achievement test given at the end of the school year. To determine the entry level of each student, the battery of criterion-referenced placement tests developed for the PEP math curriculum was administered at the beginning of the school year to each student. Each student was then given the diagnostic pretests for the units in which he was placed. The entry level score was determined by adding together the number of objectives in the units passed on the placement test and the number of specific objectives passed on the diagnostic pretests. Terminal mastery level for each student was obtained from the total number of objectives he had passed in the math curriculum by the end of the year. The Wide Range Achievement Test (Jastak & Jastak, 1965) was given at the end of the school year to obtain norm-referenced data on student learning outcomes. The test was administered by teachers to each student on an individual basis. As a measure of IQ, the Slosson Intelligence Test (Slosson, 1963) was administered in October of the kindergarten year, and again in May. The October scores were used to predict kindergarten performance; the May scores were used to predict the first grade performance. First graders who had not attended PEP kindergarten were administered the Slosson test in October of the first grade year, and these scores were used to predict their first grade performance.

Results and Discussion

Performance in the PEP Curriculum. Tables 1 and 2 summarize performance within the PEP curriculum. As shown in Table 1, both age groups mastered a large number of objectives in the course of the year (a mean of 42 for kindergarteners and 41 for first graders). Table 2 shows the end-of-year placement by unit. More than half of the kindergarten children had mastered units involving comparisons of sets (unit 5) and seriation and ordering (unit 6). Over a third had mastered addition and subtraction for quantities up to ten (unit 7) and counting and numeration for quantities up to 20 (units 9 and 10). First graders had, typically, mastered addition and subtraction (unit 7) and counting and numeration to 20, and were working on the number system using quantities up to 100.

TABLE 1

Entry and Terminal Mastery Levels in PEP Math

		Number of Instructional Objectives Mastered			
		Entry		Terminal	
Age Group	N	$\bar{X}$	S. D.	$\bar{X}$	S. D.
Kindergarten	125	3.50	6.54	45.22	19.87
First Grade	129	16.98	14.89	57.53	23.71

TABLE 2

Percent of Students Mastering Each Unit
in the PEP Mathematics Curriculum by End of School Year

Unit	Kindergarten N = 125	First Grade N = 133
1. Counting 1 – 5	96	93
2. Counting 1 – 10	90	91
3. Numeration 0 – 5	89	93
4. Numeration 6 – 10	85	81
5. Comparison of sets	86	85
6. Seriation	71	77
7. Addition & Subtraction	51	83
8. Addition & Subtraction equations	14	28
9. Counting 11 – 20	54	93
10. Numeration 11 – 20	51	86
11. Counting 20 – 100	24	56
12. Numeration 20 – 100	7	38
13. Counting 100 – 1000	2	19
14. Numeration	—	15

In order to determine the relation between mastery of the PEP curriculum and selected student characteristics a multiple regression analysis was performed using terminal mastery scores in the PEP math curriculum as the dependent variable and IQ and entry levels in each of the PEP curricula as predictors. Tables 3 and 4 give the significant (< .05) correlations among the variables. "Classification Entry" refers to the number of objectives passed on the beginning of the year placement test in the PEP classification curriculum. This curriculum covers basic concepts of "same" and "different," sorting and matching skills, and color, size, and shape terminology. "Perceptual Entry" refers to beginning of school placement in the PEP visual analysis curriculum (see Rosner, 1972), which teaches skills in visual perception.

TABLE 3

Significant Intercorrelations Among Measures of Curriculum Performance, IQ, and Achievement for Kindergarten
N = 92

	Variables					
	IQ	Classification Entry	Perceptual Entry	Math Entry	Math Terminal	WRAT
IQ	—	.33	.21		.45	.46
Classification Entry	.33	—	.22	.41	.27	.22
Perceptual Entry	.21	.22	—		.23	.31
Math Entry		.41		—		
Math Terminal	.45	.27	.23		—	.61
WRAT	.46	.22	.31		.61	—

($p < .05$)

TABLE 4

Significant Intercorrelations Among Measures of Curriculum Performance, IQ, and Achievement for First Grade
N = 125

	Variables				
	IQ	Classification Entry	Math Entry	Math Terminal	WRAT
IQ	—		.23	.32	.26
Classification Entry		—	.32	.42	.38
Math Entry	.23	.32	—	.61	.48
Math Terminal	.32	.42	.61	—	.53
WRAT	.26	.38	.48	.53	—

($p < .05$)

The perceptual curriculum was not used regularly in the first grade and scores on it were, therefore, not included in the analysis for that age group. WRAT refers to scores on the Wide Range Achievement Test, which are discussed in the next section of the paper.

Table 5 shows the results of the multiple regression analysis, together with structure R's for each predictor variable. Structure R's provide indicators of each variable's contribution to the prediction that are relatively uninfluenced by sampling variations and are more interpretable than beta weights. The higher the structure R, the greater the contribution of the predictor variable in question to explaining the total variance (Cooley and Lohnes, 1972).

TABLE 5

Multiple Correlation Analyses Between Math Terminal Mastery and Selected Student Characteristics

Criterion	Grade	N	Multiple r	Structure R: IQ	Math Entry	Classification Entry	Perceptual Entry
Math Terminal Mastery	K	92	.47	.95	.27	.56	.46
	1	125	.68	.48	.90	.62	---

Multiple r for the kindergarten group was .47; for first grade it was .68. Both were significant at the one percent level. Examining the structure R's, it is clear that at the kindergarten level, IQ was the strongest predictor of rate of progress. Classification and perceptual entry scores, which together can be viewed as a kind of general "readiness" measure, were strong secondary predictors. Entry level in the mathematics curriculum itself, however, was a poor predictor, probably because only a few children were beyond the lowest level objectives at the beginning of the year, and math entry scores were therefore clustered heavily at the bottom of the distribution.

Thus, at entry into the PEP program, the classical predictors of school achievement were also the best predictors for the present population. The picture changed sharply, however, at the first grade level, where entering position in the mathematics curriculum was the strongest predictor. Classification entry still predicted rather strongly, but the predictive power of IQ was sharply reduced in favor of a variable that reflected school performance itself rather than a generalized ability measure.

Student Performance on Standardized Achievement Measures

Wide Range Achievement Test (WRAT) scores are shown in Table 6 for the kindergarten and first grade children under study, and also for second and third graders in the same school who, in the absence of a matched control group, form a rough comparison group against which to evaluate the PEP children's performance.

TABLE 6

Comparison of Wide Range Achievement Test Results for PEP and Non-PEP Children

		Raw Score		Median
	N	$\bar{X}$	S.D.	G.E.
PEP:				
Kindergarten	103	18.05	6.6	1.4
First Grade	143	22.33	1.7	2.4
Non-PEP:				
Second Grade	98	23.21	3.8	2.3
Third Grade	104	26.99	4.4	3.0

Both the first grade and the kindergarten groups scored about five months ahead of grade level on the WRAT test. (Since WRAT was administered in May, the expected grade equivalent score for the kindergarten year was K-9; for first grade it was 1-9). By contrast, second graders, not in the PEP program, had a median score six months behind their expected grade level, and third graders were nine months behind their grade level. Thus, groups that had not participated in the PEP program showed evidence of a developing cumulative deficit, while PEP classes showed evidence of having broken the cycle by performing strongly in the kindergarten and first grade. Figure 2 shows frequency distributions by stanines for the two PEP and two non-PEP classes. Comparison of these distributions confirms the superiority of the PEP groups' performance in terms of norms for their grade levels.

In order to be certain that the observed differences between PEP and non-PEP classes were not functions of different socioeconomic status of the two groups, a comparison was made of WRAT scores of PEP students who had siblings in the second or third grade and the scores of those older siblings. Table 7 gives the data for these comparisons. The results were basically the same as for the total sample. This evidence offers further support for the positive impact of PEP on student achievement.

TABLE 7

Comparison of WRAT Results for PEP Children and Their Non-PEP Siblings

		Raw Score		Median
	N	$\overline{X}$	S.D.	G.E.
PEP:				
Kindergarten	22	19.18	6.8	1.5
First Grade	43	22.65	1.6	2.2
Non-PEP:				
Second Grade	39	23.00	3.6	2.2
Third Grade	26	27.25	4.4	3.0

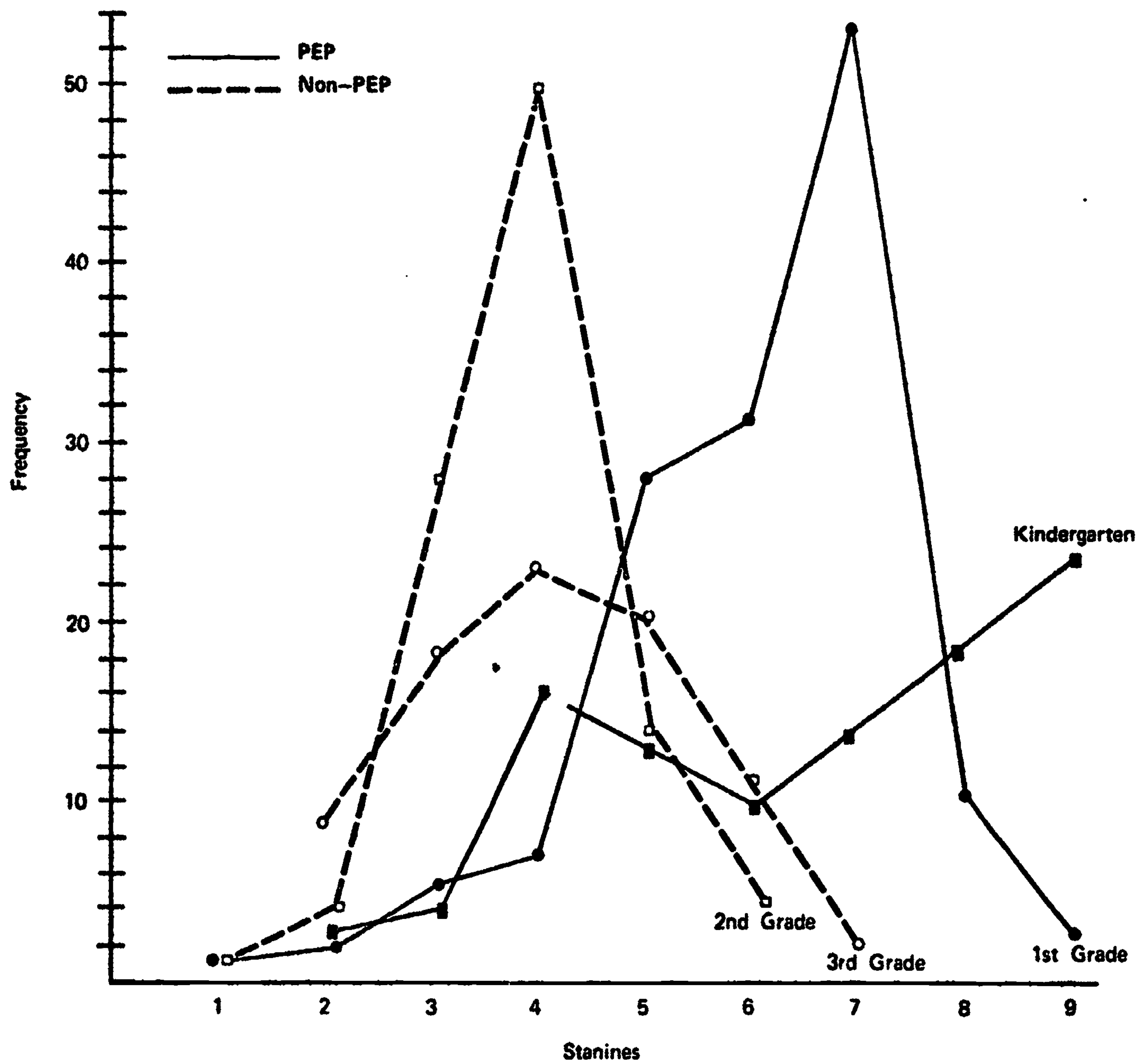

Figure 2. Comparison of PEP and Non-PEP Classes on WRAT.

A multiple regression analysis was performed using WRAT scores as the dependent variable and IQ and entry positions in the various curricula as predictors. Significant correlations on which the analyses are based appear in Tables 3 and 4. (See final columns for WRAT correlations.) Table 8 shows regression analysis results, with structure R's. Both multiple r's are significant beyond the one percent level. The pattern of structure R's is very similar to that for the math terminal equations (See Table 5). That is, IQ and entering position in the two "readiness" curricula are the strongest predictors in kindergarten; but by first grade, entering position in the math curriculum itself is the strongest contributor to prediction, and the strength of IQ as a predictor has declined sharply.

TABLE 8

Multiple Correlation Analyses Between WRAT and Selected Student Characteristics

				Structure R			
Criterion	Grade	N	Multiple r	IQ	Classification Entry	Perceptual Entry	Math Entry
WRAT	K	92	.48	.96	.46	.60	-.12
	1	125	.55	.47	.68	---	.87

The similarity of prediction patterns for terminal position in the PEP math curriculum and WRAT arithmetic scores suggest that a child's level in the math curriculum at the end of the year should strongly determine his standardized achievement test performance. Examination of the correlations of WRAT scores with terminal position in the math curriculum (See Tables 3 and 4) confirms this. For both grade levels, Math Terminal Mastery showed a strong correlation with WRAT (.61 for kindergarten; .53 for first grade). For kindergarten, terminal position in the mathematics curriculum predicted WRAT scores better than the combination of all of the entry predictors (multiple r = .48; see Table 8); for first grade, terminal math predicted WRAT scores about as well as the combined entry scores. This finding suggests that by the end of kindergarten the effect of the PEP mastery curriculum in overcoming entry level differences had already begun, and that it was well maintained in first grade, where, as we have seen, position in the math curriculum itself was the best of the entry point predictors.

The fact that student achievement in the PEP math curriculum was such a strong predictor of performance on the WRAT provides substantial evidence for the validity of the PEP math program, particularly when accompanied by strong related programs in perceptual and classification skills. This result also suggests that maximizing performance on a mastery curriculum such as PEP is a good way to raise arithmetic achievement as measured by a standardized test, particularly for poor prognosis children for whom failure is likely in a traditional program. One advantage of the PEP curriculum with its built-in assessment and diagnostic procedures, is that it allows continuous monitoring of performance both for individual children and for entire classes. Because of this, instructional strategies can be adjusted as necessary throughout the school year, creating a highly "responsive" educational program. Such responsive programs offer considerable ground for optimism concerning the possibility of breaking the cycle of cumulative deficit that continues to trouble many groups of children in America.

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