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ABSTRACT

This paper reported the results of a study designed to determine whether certain instructional strategies are superior to others in teaching problem solving to high school chemistry students. The effectiveness of four instructional strategies for teaching problem solving to students of various proportional reasoning ability, verbal and visual preference, and mathematics anxiety were compared in this aptitude by treatment interaction study. Strategies used were: (1) the factor-label method; (2) the use of analogies; (3) the use of diagrams; and (4) proportionality. Problem solving ability of high school students (N=609) in nine schools in Indiana was measured by a series of immediate post-tests given after each lesson of an instructional unit, delayed post-tests given within two weeks of each unit, and the ACS-NSTA Examination in High School Chemistry administered at the end of the year. Findings indicate: (1) that mathematics anxiety is negatively correlated with science achievement; (2) that problem solving ability in chemistry is dependent on students' proportional reasoning ability; and (3) that students with visual preference performed better on an immediate post-test dealing with the topic of molarity. (DS)

Facilitating Problem Solving

in High School Chemistry

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One of the basic skills required of high school chemistry students is problem solving. Students frequently lack proficiency in this area yet little research has been conducted that examines strategies that might be used to improve students' problem solving skills.

Chemistry teachers present problem solving to their students in a variety of ways. Some of these methods are more visual, other more verbal. Some are more mathematical, others more descriptive. The use of different strategies in teaching problem solving can be seen in relation to the memory structures presented by Gagne and White (1978) as shown in Figure 1.

Insert Figure 1 about here

They postulated that there were four memory structures that lead to knowledge stating and rule application. Both of these are necessary components of problem solving in chemistry. Two instructional strategies that teachers use, analogies and diagrams, are considered to be related to the memory structure "images" whereas two others, the factor-label method and proportionality are more directly related to the memory structure "intellectual skills". The question of whether this additional use of the memory structure "images" would enable students to solve problems more effectively was examined in this research. The work of Paivio (1969, 1971) supports the idea that students of varying verbal or visual preference might perform differently on verbal or visual approaches to learning. Research in science education that has been done by Holliday (1975, 1976a,b) to determine the effectiveness of verbal, visual, and combined approaches points to the superiority of a combined verbal-visual approach versus a verbal approach in learning science concepts. Earlier work by Weisberg (1970), Dwyer (1972) and Arnold and Dwyer (1975) supports the claim that both adults and children learn concepts better when pictures or images are presented. No attempt was made in the aforementioned studies, however, to determine whether particular approaches were dependent on students' verbal or visual preferences nor to examine the effect on students' problem solving ability rather than concept formation.

Two other factors that appear to be related to students' problem solving ability are proportional reasoning ability and mathematics anxiety. Proportional reasoning ability is one of the schema that comprises the formal operational stage which as been shown to be related students' success in learning chemistry (Ward and Herron, 1980). Wheeler and Kass (1977) found that students success in chemistry, particularly their problem-solving ability, was dependent on students' proportional reasoning ability. This has particular significance for high school chemistry teaching because a number of researchers have indicated that at least 50% of high school students do not operate on the formal operational level (Chiappetta, 1976, DeCarcer et al, 1978, Lawson and Renner, 1974). In the conclusions of their study, Wheeler and Kass suggested as did Herron (1975), that the use of the factor-label method may aid students in overcoming this proportionality handicap.

In the past few years there has been increased interest in mathematics anxiety. Auslander (1977), Blum (1977), Mitzman (1976), Sells, (1978) and Tobias (1978) have shown that persons suffer from anxiety that is stimulated when they are in mathematical problem solving situations. Barnes (1977) has shown that mathematics anxiety is a predictor of semester grades for lower division physics students. Sherwood and Gabel (1980) found that it was a weak predictor of success in a basic science skill course for preservice elementary teachers. Because chemistry problem solving involves the extensive use of mathematics, the relationship between mathematics anxiety and chemistry problem-solving ability was examined in this research.

Purpose

The major purpose for conducting this study was to determine whether certain types of instructional strategies were superior to others in teaching high school students' problem solving in four topics integral to every chemistry course. These topics were the mole concept, the gas laws, stoichiometry, and molarity. In all four areas, the problems require similar algebraic and proportional reasoning skills. Also of major interest was whether particular strategies would be more effective for students having different verbal-visual preferences, varying proportional reasoning ability, and different levels of mathematics anxiety.

The four strategies used in teaching students to solve chemistry problems were the factor-label method, proportionality, the use of analogies and the use of diagrams. The first two strategies were considered to be more mathematical and verbal approaches and the latter two more visual and less mathematical in nature.

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Procedures and Design

Sample

The sample consisted of 609 high school chemistry students of ten teachers in eight schools in central and south central Indiana. Types of schools included inner city, suburban, small town, and rural. Data were analyzed for the 421 students who completed the entire experiment that lasted one school year. Students were randomly assigned to the four instructional strategies used within each classroom.

Design

The design for this aptitude by treatment interaction study was basically a "posttest only, control group design". It is summarized in Figure 2.

Insert Figure 2 about here

Treatments

Self-instructional booklets were prepared to teach each of the four chemistry topics according to each of the four teaching strategies. Each unit had three to four lessons consisting of an introduction, the concepts, and a summary with extra practice problems. The booklets were approximately the same length and were color coded according to each teaching strategy to facilitate the use of all four strategies simultaneously in each classroom. A chemist and two chemistry educators critiqued the booklets for appropriate chemistry content and pedagogy. The booklets were revised according to their suggestions.

At the beginning of the 1979-1980 school year teachers randomly assigned each student in their classes to a particular teaching strategy for the entire year. When the teacher reached the appropriate section in the text where the particular concept was to be taught, the self-instructional booklets were used in place of the regular instruction. Individual lessons were distributed at the beginning of the period. Students completed the body of the lesson and then worked on the supplementary practice problems (to control instructional time) until the end of the period when the lessons were collected and immediate posttests were administered. (If a lesson required two days to complete, teachers collected the booklets and redistributed them the following day).

Students were then provided with a review sheet that contained a brief summary of the method that they could use to study for the delayed posttest. These were administered within two weeks of the last lesson of each unit.

The ACS-NSTA Cooperative Examination in High School Chemistry and a questionnaire on the usefulness of the booklets were administered at the end of the school year. Teachers' use of the units was monitored by visits to their classrooms during and immediately following the instructional treatments.

The four instructional methods had some commonalities, but each differed substantially from the others. The focus of the factor-label method was on the importance of estimating methods to obtain correct answers by looking at the units of the given values. Students were shown how the units 'cancel out' in the calculations and how correct answers may be determined by looking at the units of the answer. For example, in the problem, "If a sample O_2 gas had a volume of 89.6 liters at STP, how many moles would be represented?", the factor-label method would indicate to the student that they should set up their factor (1 mole = 22.4 liters) so that the liters would cancel:

$$89.6 \text{ liters } O_2 \times \frac{1 \text{ mole}}{22.4 \text{ liters}} = 4 \text{ moles } O_2$$

The analogy method used common examples to help students understand the relationship needed to solve the problem. For the above problem, the example was that of a shipping carton of fruit. Regardless of the size of the fruit, the volume for a dozen fruit was always 3 pints. The problem, "How many dozen oranges would fit into a delivery box that had a volume of 54 pints?" was worked immediately before the 89.6 liters of O_2 problem was shown. Mathematically the analogy problems were set-up to the diagram problems:

$$\frac{89.6 \text{ liters } O_2}{22.4 \text{ liters/mole}} = 4 \text{ moles } O_2$$

The diagrammatic method for this example problem used the diagram pictured in Figure 3. Students were shown that certain steps (boxes on the diagram).

Insert Figure 3 about here

must be taken in order to reach the desired answer. Mathematically, when multiplication was used, the diagrammatic and factor-label methods used the same set-up. When division was indicated by the diagram, however, set-ups differed in that the factor-label method used multiplication by a reciprocal rather than division. The gas law problem was set up as:

$$\frac{89.6 \text{ liters } O_2}{22.4 \text{ liters/mole}} = 4 \text{ moles } O_2$$

The proportionality method used the format of $\frac{A}{B} = \frac{C}{X}$ to help students determine the value of X. While the fact that the units 'cancel out' to yield reasonable units for the answer was discussed, this was not emphasized. For the gas volume problem, the students were shown that the problem could be solved by the use of a simple proportion: $\frac{X}{89.6 \text{ liters } O_2} = \frac{1 \text{ mole}}{22.4 \text{ liters}}$

$(x)\ (22.4 \text{ liters}) = (89.6 \text{ liters } O_2)\ (1 \text{ mole}) \quad X = \frac{(89.6 \text{ liters } O_2)\ (1 \text{ mole})}{(22.4 \text{ liters})}$

$= 4 \text{ moles } O_2$

While all the methods had differences, the canceling of units was carried out in all four types.

Instruments for Measuring Aptitudes

Verbal-Visual Preference. A 54 item subset of an 86 item questionnaire developed and modified by Paivio (1979) was used to measure students' verbal and visual preference. Reliabilities (α) using data from this study for the two subscales were .84 and .73 respectively. The test consists of a series of statements with which the student agrees or disagrees about ways in which they prefer to learn. Administration time was 20 minutes.

Proportional Reasoning Ability. A modified form of the formal operation test developed by Staver (1978) was used to measure students' proportional reasoning ability. The proportional reasoning section of the instrument was expanded from two tasks (Mr. Short-Mr. Tall, Balance Beam) to four tasks by including the "two cylinders task" of Lawson (1978) and the "disks task" of

Wollman and Lawson (1978). This resulted in a 21 item paper and pencil test with video-taped demonstrations that includes both numerical and reasoning questions with an alpha reliability of .85.

Mathematics Anxiety. Students' mathematics anxiety was measured using the Mathematics Anxiety Rating Scale developed by Suinn (Suinn et. al., 1972). The instrument consists of a 98 item self-rating scale in which students are asked to describe the degree of anxiety aroused from different anxiety-producing situations. Administration of the scale, which had an alpha reliability of .97, required 20 minutes.

Dependent Measures

Nine dependent measures (an immediate and delayed posttest for each of the four units and a final examination) were administered to determine students' problem solving ability. In addition, a questionnaire on the use of the self-instructional materials was given at the end of the school year.

Immediate Posttests. Students' immediate ability to solve numerical chemistry problems for each unit of instruction was measured by their scores on short tests given after each lesson within a given unit. Each of the four units (moles, gas laws, stoichiometry and molarity) contained three or four lessons that took one to two days to complete. When a student completed a lesson, he was administered a multiple choice test of 4 - 6 items that contained problems similar to those taught in the lesson. Although the test questions for each treatment were identical, a short reminder of the treatment technique was printed at the top of the first page of each test. This was done in order to encourage students to learn to solve the problems by the method presented in their own booklets and to discourage exchanging booklets with their friends. Due to the short length of these tests, their proximity of administration, and their similar domain of instruction, scores from tests on individual lessons were summed to produce an immediate posttest score for each unit.

All of the test items were critiqued by a chemist and two chemistry educators (not associated with the development) for accuracy and appropriateness for the unit. Alpha reliabilities ranged from .66 - .76.

Delayed Posttests. Within two weeks after completing all lessons in a given unit, teachers administered the delayed posttests for each unit. These were ten item multiple choice tests that contained problems similar to those taught in the unit plus transfer items. These items were also scrutinized by a chemist and two chemistry educators. Alpha reliabilities ranged from .69 - .81.

ACS-NSTA Chemistry Achievement Test. The ACS-NSTA Cooperative Examination, High School Chemistry Form 1975, Part I was administered by classroom teachers during the final month of the school year after all four instructional units had been completed. In several schools both the regular and scrambled version of the test were given to eliminate the possibility of cheating. This test is commonly given in schools as a final examination and measures facts, concepts, and problem solving skills. Part I of the 1975 examination was selected because it contained the largest number of items that were related to the problems taught in the instructional units. It contains 40 items and has an administration time of 40 minutes. The alpha reliability of the regular form was found to be .75 (n = 410) and the scrambled form .55 (n = 146).

Results

Data were analyzed using multiple linear regression techniques. 'Dummy' variables were coded by the treatment effects and these were used to produce interaction variables with the aptitudes. Of the several methods available for this coding (Cohen and Cohen, 1975, Chapter Five) effects coding was the most appropriate. In effects coding, the method takes as its reference point all of the groups taken a equally weighted aggregate. The null hypothesis under test is that the dependent variable mean for group i is equal to the means of the dependent variable of all the groups.

The order of entering the variables into the regression equation was based on "weakness" of the aptitude. The verbal and visual aptitudes were entered first (on an equal basis) because from a review of the literature they appeared to have the least construct validity. Mathematics anxiety ratings and proportional reasoning ability had increasing degrees of construct validity in the order stated. By placing verbal preference, visual preference, and mathematics anxiety into the regression equation before proportional reasoning ability, any shared variance would be considered in the weaker constructs. This would have the proportional reasoning ability aptitude uncontaminated by the shared variance (Cohen and Cohen, 1975, p. 327).

This study utilized univariate multiple regression as an analytical tool rather than multivariate linear regression because four different chemistry topics were studied, the multivariate analysis would have been most difficult to interpret due to the nine dependent variables and correlations between dependent variables were modest. In the instance where the correlation was greatest (moles and stoichiometry), data were analyzed using the multivariate analysis (Sherwood, 1980), and results were found to be consistent with the approach used in this study.

Results of the study are summarized in Table 1 which shows significant main effects and the first and second order interaction effects when these were significant. No third order interactions were found to be significant.

Insert Table 1 about here

Table 2 displays the regression coefficients and change in R^2 for the main effects of the four aptitudes considered in the study.

Insert Table 2 about here

From Tables 1 and 2 it can be seen that verbal preference was not related to achievement and visual preference was related in only one instance. Students with a visual preference to learn performed better on the Molarity Immediate Posttest.

Both mathematics anxiety and proportional reasoning ability were related to students' performance on all dependent measures. In every instance students with high mathematics anxiety had lower achievement. The percentage of variance accounted for varied from 1% to 3%. There was a significant positive correlation between students' proportional reasoning ability and achievement with the percentage of variance accounted for ranging from 3% to 19%.

The particular strategy that students used to learn how to solve chemistry problems in the four units of instruction had a significant effect on achievement on three dependent measures as can be seen from Table 1. Regression equations are shown in Table 3. Table 4 shows that for the Moles Immediate

Insert Table 3 about here

Posttest, the factor-label method was best and the proportionality method

Insert Table 4 about here

poorest. For the Gas Laws Immediate Posttest, the use of analogies and diagrams was poorest and proportionality best and for the Delayed Posttest, the use of analogies poorest.

The only first order interaction that was significant was a visual preference by treatment interaction on the ACS-NSTA Chemistry Test as shown in Figure 4. Regression equations are given in Table 5. Students

Insert Figure 4 and Table 5 about here

with low visual preference using the analogy treatment scored highest on this test.

There were four second order aptitude by treatment interactions that were found to be significant: verbal preference by visual preference on the Moles Immediate Posttest, visual preference by mathematics anxiety on the Stoichiometry Immediate Posttest, verbal preference by proportional reasoning ability on the Molarity Delayed Posttest, and mathematics anxiety by proportional reasoning ability on the Gas Laws Immediate Posttest. Regression coefficients and equations are given in Table 6. Figures 5 through 8 show the results pictorially.

Insert Table 6 and Figures 5 - 8 about here

For students with low visual preference and high verbal preference, the analogy and diagram method were best. However, for students with both low verbal and visual preference these methods were poorest. Although results for the immediate posttest of the other units were not significant and are not given here because of space limitations, the same trend was found for the Gas Laws Immediate Posttest.

Figure 6 shows the results for the visual preference by mathematics anxiety interaction. The factor-label, analogy, and diagram methods interacted significantly. For students with low visual preference and low mathematics anxiety, the factor-label method was superior and the diagrammatic method inferior. However, this was not the case for low visual students who had high mathematics anxiety. For them, the diagrams were best and the factor-label poorest. A similar trend was found for the moles unit although analogies were almost as useful for the low visual-high mathematics anxious student. For the gas laws unit differences between treatments were almost negligible. For the molarity unit, however, the diagrams were superior and proportionality inferior for the low visual preference-high mathematics anxious students. The exact opposite trend was found for the low visual-low mathematics anxious students.

For students with low proportional reasoning ability and low verbal preference, Figure 7 shows that the analogy method was best for students of low proportional reasoning ability and low verbal preference or high proportional reasoning ability and high verbal preference. When just one of the aptitudes was low, the analogy method was the poorest approach. These results were not found to be consistent across the other three units.

Figure 8 shows that for students with high mathematics anxiety and low proportional reasoning ability, the analogy method was the best and the factor-label method the worse. This was reversed for students of low proportional reasoning ability and low mathematics anxiety. These results for the factor-label method were the same as those found for students of low visual preference and high mathematics anxiety on the Stoichiometry Immediate Posttest (Figure 6). For the other units, although results were not significant, in every case, the factor-label method was best for students of low mathematics anxiety and low proportional reasoning ability, and for two out of the three units, was the poorest for students of high mathematics anxiety and low proportional reasoning ability.

Summary and Conclusions

This aptitude by treatment interaction study has shown that the aptitudes of mathematics anxiety and proportional reasoning ability are related to students' success in solving problems in high school chemistry. Students of high mathematics anxiety scored significantly lower than students of low mathematics anxiety. Students of high proportional reasoning ability scored higher than students of low proportional reasoning ability. Both of these findings are not surprising. They confirm the research of Barnes (1977), Sherwood and Gabel (1980) and Wheeler and Kass (1977). Teachers are probably more aware of the relationship of proportional reasoning ability and success in problem solving than the mathematics anxiety relationship. As teachers become more aware of the latter they will probably incorporate into their lessons, teaching strategies that will reduce this anxiety.

Certain methods used in this study were less mathematical and more visual than others. These were the use of analogies and the use of diagrams. The more mathematical were the factor-label method and proportionality. The best method in general (main effect) for the moles unit where less contamination could be expected (used first in all classrooms) was the factor-label method and the worse method was proportionality. For the gas laws, however, in which the laws themselves are stated as proportions, the proportionality method was most effective and diagrams and analogies least effective. These results show that either the teaching strategies are subject matter specific or that the proportionality method becomes more effective over time (the gas laws were studied later in the school year in most instances).

The verbal and visual preference of students was found to have little relationship in general to students' success in solving chemistry problems as is indicated by the failure to find main effects consistently for all dependent measures. The significant first order interaction for visual students and the analogy treatment on the ACS-NSTA Chemistry Examination indicates that there may be a relationship between students' visual preference and the type of teaching strategy used for instruction. It was anticipated that low visual students would do best with the least visual approaches. The use of analogies which was considered a visual approach was found to be superior for low visual students. One possible explanation for this is that even though these students did not prefer this approach, it required them to pay greater attention to the material at hand. Because students prefer to learn by a certain approach, does not necessarily mean that they learn better using this approach.

Of more importance than the main effects and first order interaction effects in this study were the second order aptitude by treatment interaction findings. Of greatest interest are the results found for students of high mathematics anxiety and low scores on another aptitude. For students of this type, the less mathematical approaches frequently appear to be superior. It was found to be rather consistently true that the diagram method was superior and the factor-label method inferior for students of high mathematics anxiety and low visual preference for the immediate posttests for the four chemistry units (significant or trend in that direction). For students having high mathematics anxiety and low proportional reasoning ability, the analogy method, the other less mathematical strategy, was best (significant) followed by the diagram method for the Gas Laws Immediate Posttest. The factor-label method was the worst. Although not significant, the diagram method appeared to be somewhat better in two of the other three units on this same dependent measure.

These results seem to indicate that students with high mathematics anxiety and the absence of another aptitude (visual preference or proportional reasoning ability) profit by methods that contain supportive material that is not mathematical in nature. Analysis of the questionnaire administered at the end of the school year substantiates this. Some students mentioned that they did not use the analogies or diagrams but skipped to the sample problems. These students were likely to be the low mathematics anxious students. (There was no way to check on this because students answered questionnaires anonymously.) However, other students commented that they found the diagram and analogies beneficial and particularly so when they didn't understand the sample problems. Several commented that that is when they used the analogies or diagrams. These were probably the more mathematics anxious students.

These findings indicate that it would be profitable for teachers to use supplemental, less mathematical and more visual approaches with high mathematics anxious students who also are deficient in proportional reasoning ability or have low visual preference. Apparently the combined verbal-visual approach shown to be superior for concept learning by Holliday (1975, 1976a,b) is effective for certain groups of students in learning to solve chemistry problems. Certainly, the factor-label method should not be used exclusively for these types of students. Because students' proportional reasoning ability develops over time, if these students have had successful experiences in solving problems in high school chemistry, their mathematics anxiety may diminish and they may elect scientific related careers.

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Table 1

Summary of Results of Aptitude x Treatment Interaction Study

Effect	MO IT	GL IT	S IT	ML IT	MO DT	GL DT	S DT	ML DT	ACS TOT
V or I				.01[b]					
M	.01[a]	.01	.01	.01	.05	.01	.01	.01	.01
P	.01	.01	.01	.01	.01	.01	.01	.01	.01
Treatments	.01	.01				.05			
P	.01	.01							
A		.01				.01			
D		.05							
F	.05								
V or I x Treatments									.05[b]
V or I x D									
V or I x A									.01[b]
V or I x D									
V or T x F									
V x I x Treatments	.01								
V x I x F									
V x I x A	.05								
V x I x D	.05								
V x I x P									
V or I x M x Treatments			.05[b]						
V or I x M x F			.01[b]						
V or I x M x A			.05[b]						
V or I x M x D			.01[b]						
V or I x M x P									
V or I x P x Treatments								.05[c]	
V or I x P x F									
V or I x P x A								.05[c]	
V or I x P x D									
V or I x P x P									
M x P x Treatments		.05							
M x P x F		.05							
M x P x A		.05							
M x P x D									
M x P xP									

[a] Level of significance
[b] I - Visual
[c] V - Verbal

Treatments
- Factor-Label (F)
- Analogy (A)
- Diagram (D)
- Proportionality (P)

Units
- Moles (MO)
- Gas Laws (GL)
- Stoichiometry (S)
- Molarity (ML)

Aptitudes
- Verbal (V)
- Visual (I)
- Proportional Reasoning (P)
- Mathematics Anxiety (M)

Dependent Measures
- Immediate Posttest (IT)
- Delayed Posttest (DT)
- ACS-NSTA Examination in H. S. Chem. (ACSTOT)

Table 2

Main Effects Summary

Dependent Measures	V B	V ΔR^2	I B	I ΔR^2	MARS B	MARS ΔR^2	PPRT B	PPRT ΔR^2
MOIT	-.0240	.0001	+.0392	.0022	-.0007	.0241	+.2006	.0744
GLIT	-.0249	.0006	+.0298	.0034	-.0051	.0202	+.0700	.0302
SIT	-.0140	.0004	+.0375	.0015	-.0076	.0244	+.0244	.0725
MLIT	-.0154	.0013	+.1122	.0223	-.0055	.0150	+.1583	.0623
MODT	+.0052	.0017	+.0269	.0036	-.0016	.0103	+.1735	.1125
GLDT	-.0316	.0020	+.0220	.0019	-.0048	.0131	+.1305	.0664
SDT	-.0317	.0005	-.0193	.0005	-.0090	.0356	+.1737	.0818
MLDT	-.0068	.0000	+.0109	.0002	-.0061	.0231	+.1460	.0595
ACSTOT	-.0197	.0002	-.0356	.0018	-.1026	.0302	+.5486	.1867

Units
- Moles (MO)
- Gas Laws (GL)
- Stoichiometry (S)
- Molarity (ML)

Aptitudes
- Verbal (V)
- Visual (I)
- Proportional Reasoning (MARS)
- Mathematics Anxiety (PPRT)

Dependent Measures
- Immediate Posttest (IT)
- Delayed Posttest (DT)
- ACS-NSTA Examination in H. S. Chemistry (ACSTOT)

Table 3

Regression Equation for Different Teaching Strategies

MOIT	=	$-.00675(MARS) + .197(PPRT) - .887(X3) + .0471(X2) + .404(X1) + 16.018$
GLIT	=	$-.00460(MARS) + .0780(PPRT) + .767(X3) - .379(X2) -.356(X1) + 10.024$
GLDT	=	$-.00390(MARS) + .153(PPRT) + .383(X3) - .469(X2) -.168(X1) + 6.095$

MOIT = Moles Immediate Posttest

GLIT = Gas Laws Immediate Posttest

GLDT = Gas Laws Delayed Posttest

MARS = Mathematics Anxiety ($\overline{MARS}$ = 184.56)

PPRT = Proportional Reasoning Ability ($\overline{PPRT}$ = 12.614)

Table 4

Predicted Values for Different Teaching Strategies

		Predicted Value		
Strategy	Dummy Variable	MOIT	GLIT	GLDT
Proportion	X3 = 1	16.37[a]	10.93[b]	7.68
Analogy	X2 = 1	17.30	9.78[a]	6.83[a]
Diagram	X1 = 1	17.66	9.80[a]	7.13
Factor-Label	X3 = X2 = X1 = -1	17.69[b]	10.13	7.56

[a]Significantly lower than mean

[b]Significantly higher than mean

MOIT = Moles Immediate Posttest (maximum score = 21)

GLIT = Gas Laws Immediate Posttest (maximum score = 12)

GLDT = Gas Laws Delayed Posttest (maximum score = 10)

Table 5

Regression Coefficients and Equations for

Visual Preference (VVQI) X Treatment (X1-X3) Interaction

Strategy	B	Equation
Proportion	+.158	ACSTOT = .1538I + 15.115
Analogy	-.287	ACSTOT =-.33841I + 24.289
Diagram	+.042	ACSTOT =-.0194I + 17.912
Factor-Label	+.087	ACSTOT = .0615I + 16.732

ACSTOT = ACS-NSTA Achievement Test

Table 6

Regression Coefficients and Equations for Second Order Interactions

Interaction	Strategy	B	Equation
Verbal Preference X Visual Preference X Treatment	Proportion	+.024	MOIT = -.658V-.390I+.0337VI+24.41
	Analogy	-.023	MOIT = +.619V+.394I-.0295VI+8.95
	Diagram	-.019	MOIT = +.241V+.240I-.0180VI+14.36
	Factor-Label	+.019	MOIT = -.285V-.074I+.0133VI+19.28
Visual Preference X Mathematics Anxiety X Treatment	Proportion	+.001	SIT = +.042I-.012M+.0004IM+10.84
	Analogy	-.002	SIT = +.121I-.001M-.0009IM+9.18
	Diagram	-.002	SIT = +.381I+.031M-.0019IM+2.98
	Factor-Label	+.003	SIT = -.314I+.048M+.0020IM+17.53
Verbal Preference X Proportional Reasoning Ability X Treatment	Proportion	+.0026	MLDT = -.056V+.105P+.0011VP+5.23
	Analogy	+.0147	MLDT = -.205V-.138P+.0168VP+7.74
	Diagram	-.0106	MLDT = +.135V+.406P-.0119VP+1.20
	Factor-Label	-.0068	MLDT = +.097V+.210P-.0058VP+3.43
Mathematics Anxiety X Proportional Reasoning Ability X Treatment	Proportion	-.0004	GLIT = -.11M-.067P+.0006MP+12.57
	Analogy	-.0017	GLIT = +.013M+.344P-.0015MP+6.52
	Diagram	-.0005	GLIT = +.011M+.282P-.0009MP+6.31
	Factor-Label	+.0018	GLIT = -.033M-.277P+.0017MP+15.64

MOIT = Moles Immediate Posttest
SIT = Stoichiometry Immediate Posttest
MLDT = Molarity Delayed Posttest
GLIT = Gas Laws Immediate Posttest

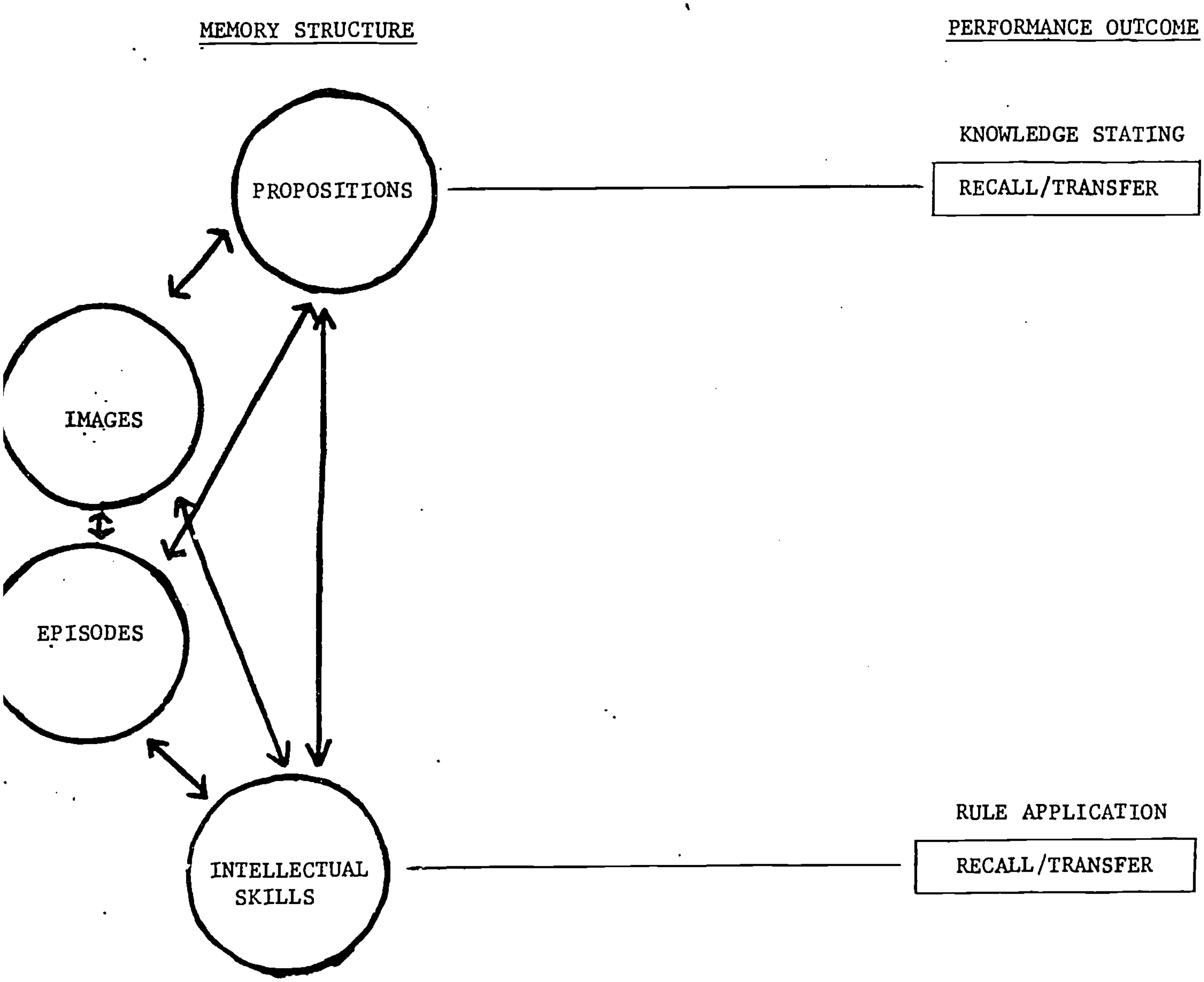

Figure 1. Memory structures and learning outcomes. (Modified from Gagne and White, 1978).

$A\ R\quad W_1O_1\ W_2O_2\ W_3O_3\ W_4O_4\quad O_5\quad X_1O_1\ X_2O_2\ X_3O_3\quad O_5\quad Y_1O_1\ Y_2O_2\ Y_3O_3\quad O_5\quad Z_1O_1\ Z_2O_2\ Z_3O_3\quad O_5\quad O_6$

$A\ R\quad W_1O_1\ W_2O_2\ W_3O_3\ W_4O_4\quad O_5\quad X_1O_1\ X_2O_2\ X_3O_3\quad O_5\quad Y_1O_1\ Y_2O_2\ Y_3O_3\quad O_5\quad Z_1O_1\ Z_2O_2\ Z_3O_3\quad O_5\quad O_6$

$A\ R\quad W_1O_1\ W_2O_2\ W_3O_3\ W_4O_4\quad O_5\quad X_1O_1\ X_2O_2\ X_3O_3\quad O_5\quad Y_1O_1\ Y_2O_2\ Y_3O_3\quad O_5\quad Z_1O_1\ Z_2O_2\ Z_3O_3\quad O_5\quad O_6$

$A\ R\quad W_1O_1\ W_2O_2\ W_3O_3\ W_4O_4\quad O_5\quad X_1O_1\ X_2O_2\ X_3O_3\quad O_5\quad Y_1O_1\ Y_2O_2\ Y_3O_3\quad O_5\quad Z_1O_1\ Z_2O_2\ Z_3O_3\quad O_5\quad O_6$

Where:

A = Aptitude measures (proportional reasoning test, mathematics anxiety test, and verbal-visual preference).

R = Random assignment of subjects to treatments.

WXYZ = The instructional treatments on the four chemistry topics (moles, gas laws, stoichiometry, and molarity. Subscripts indicate the four treatments, factor-label, analogies, diagrams, and proportionality).

O_1-O_4 = Immediate posttests given after each lesson. These scores were summed for the analysis.

O_5 = Delayed posttests.

O_6 = ACS-NSTA Examination in High School Chemistry.

Figure 2. Summary of design for aptitude x treatment interaction study.

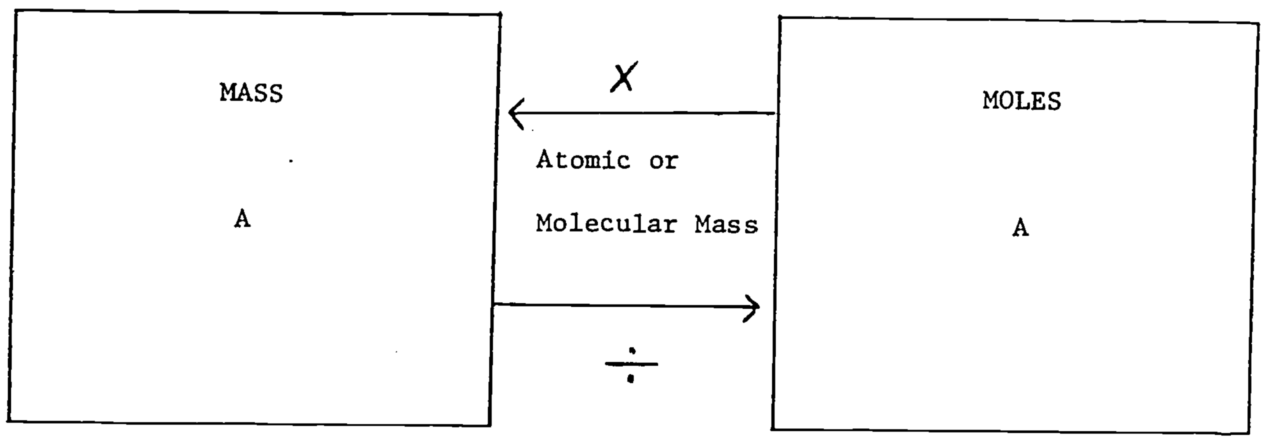

Figure 3. Schematic diagram for solving moles problems.

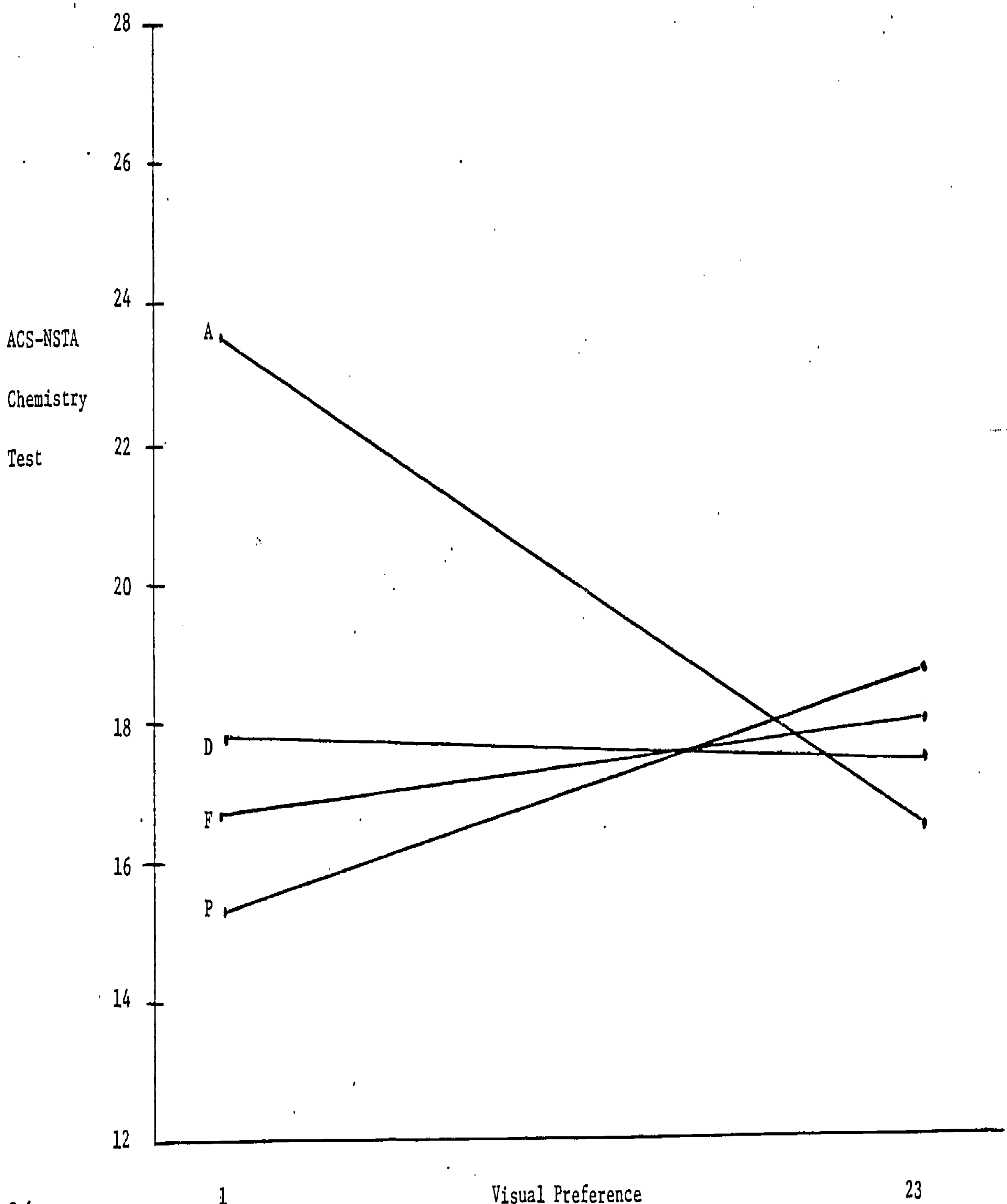

Figure 4. ACS-NSTA Chemistry Achievement Test (ACSTOT): Visual Preference (I) X Treatment (X1-X3) Interaction

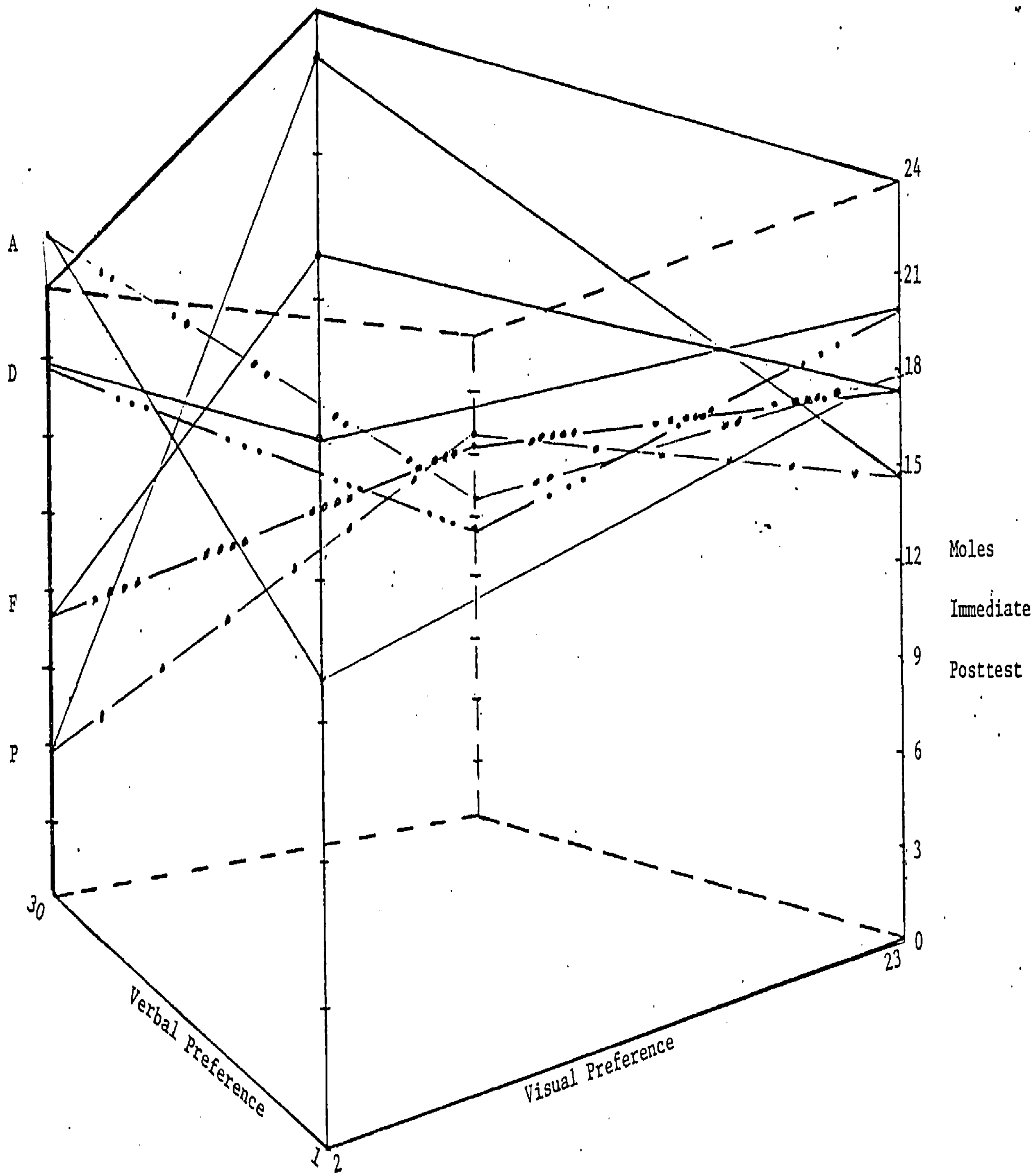

Figure 5. Moles Immediate Posttest (MOIT): Verbal Preference(V) X Visual Preference (I) X Treatment (X1-X3) Interaction

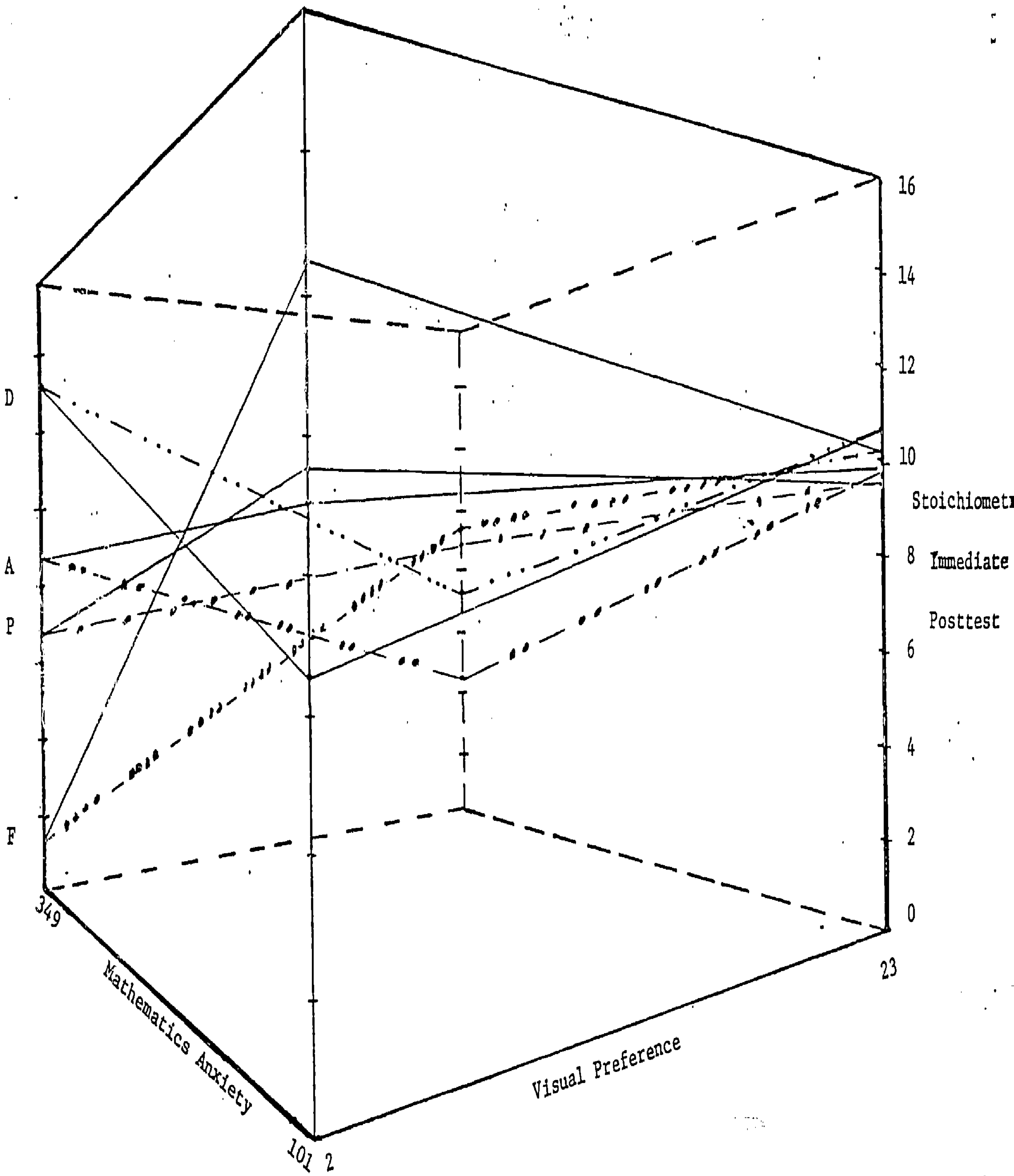

Figure 6. Stoichiometry Immediate Posttest (SIT): Visual Preference (I) X Mathematics Anxiety (MARS) X Treatment (X1-X3) Interaction

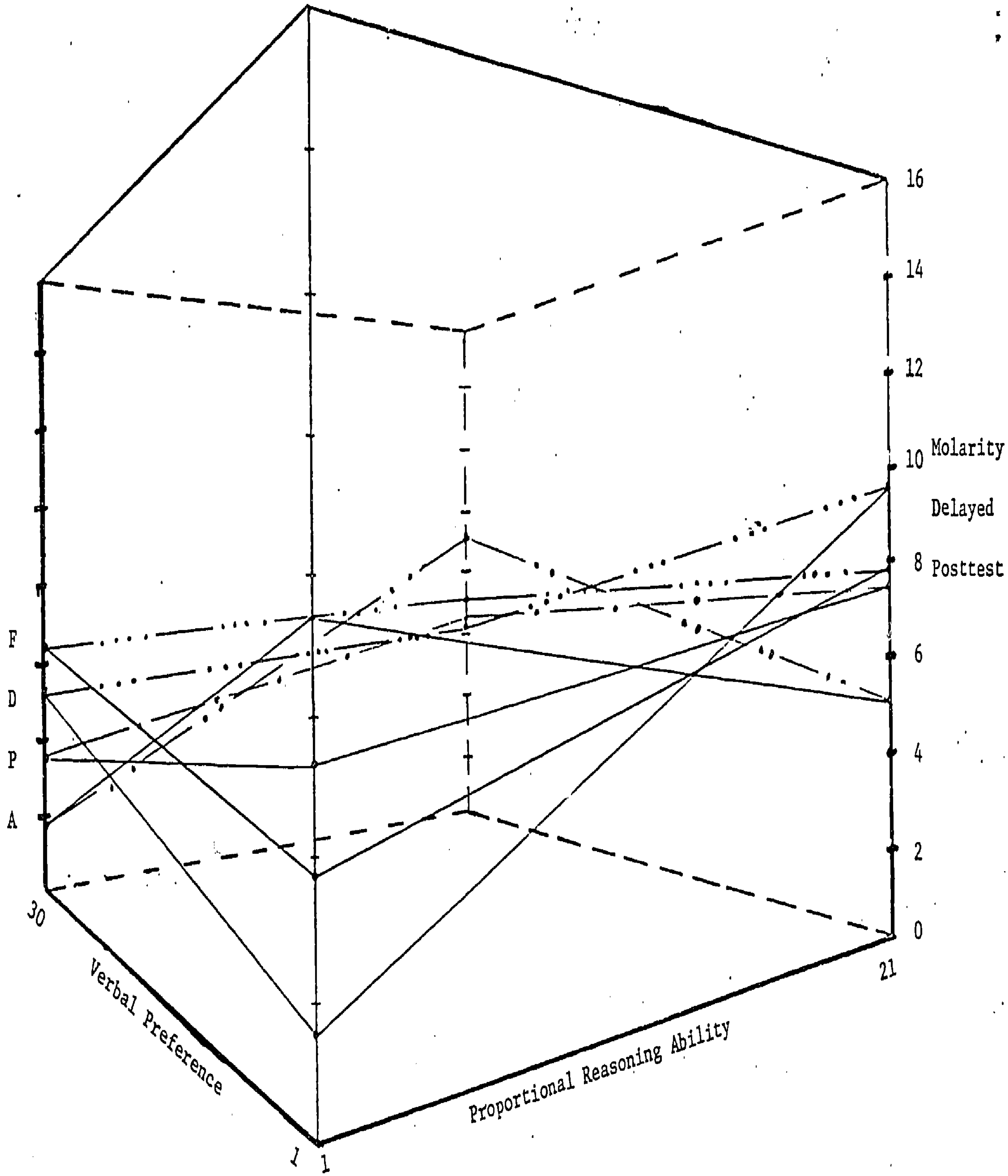

Figure 7. Molarity Delayed Posttest (MLDT): Verbal Preference (V) X Proportional Reasoning (PPRT) X Treatment (X1-X3) Interactions

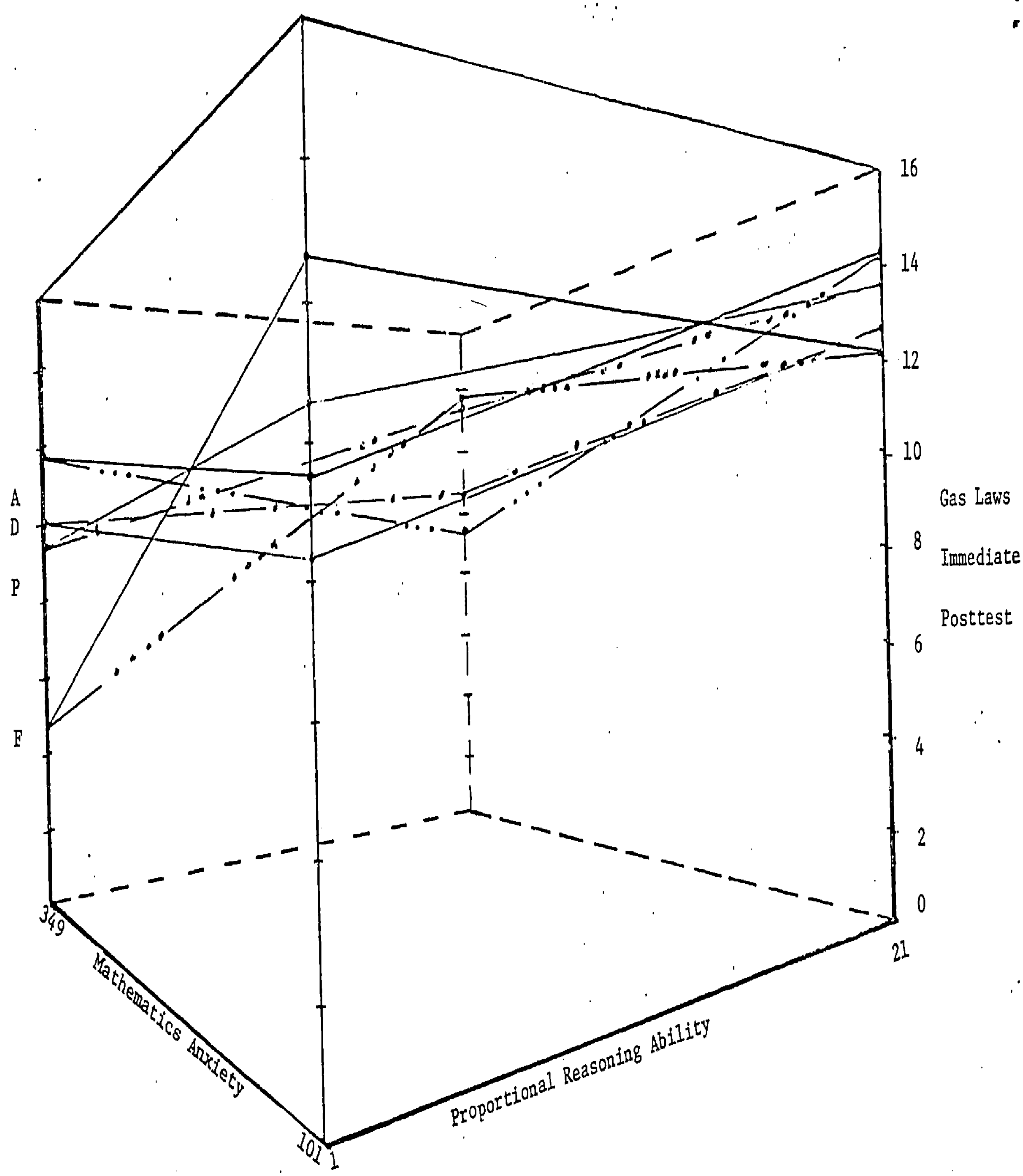

Figure 8. Gas Laws Immediate Posttest (GLIT): Mathematics Anxiety (MARS) X Proportional Reasoning Ability (PPRT) X Treatment (X1-X3) Interaction