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TRAINING MATHEMATICS SKILLS WITH GAMES

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The goal of this study was to test the efficacy of using games presented on the PLATO IV instructional system to provide remedial mathematics training for Basic Electricity/Electronics (BE/E) School trainees.

Two learning tasks which provide the most difficulty for students were selected and instructionally programmed for the PLATO IV system. Drill and practice routines for the two tasks were prepared in three methods. Two games

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were designed which utilized PLATO IV display capabilities, along with a conventional problem presentation followed by answer feedback routine. A group of students was assigned to each of the counterbalanced order of the independent tasks. Within each group, students received one of the six possible combinations of the three methods (conventional and two games).

No significant differences in performance or training time measures were found between the three training methods. Questionnaire data indicated that students who experienced both game mathematics practice and conventional practice definitely preferred game practice.

Effectiveness of game displays is dependent on reliable PLATO IV system operation. It was observed that the effectiveness of using games as an instructional technique suffered more than that of the conventional method when hardware and software operations were unstable.

Due to favorable student reaction to game practice, further development and evaluation of instructional games are warranted.

FOREWORD

This study was performed under ADO 43-03X, subproject P43-03X.03a, Experimental Evaluation of PLATO IV Technology. Hardware and communications costs were paid for by the Defense Advanced Research Projects Agency, Human Resources Office.

Successful completion of this study was due largely to the assistance of the staff of the Basic Electricity/Electronics School, Service School Command, San Diego. Chief Lee and Instructor Hovda were particularly helpful in providing students for the study and in gathering student background data.

Mr. Anthony Sassano, Mrs. Betty Whitehill, and Mr. Terry Tibbetts generously contributed their invaluable aid in TUTOR programming and data management. Dr. Dewey A. Slough assisted greatly in the design of this study and in providing data analysis expertise.

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Commanding Officer

SUMMARY

Purpose

The goal of this study was to test the efficacy of using games presented on the PLATO IV instructional system to provide remedial mathematics training for Basic Electricity/Electronics (BE/E) School trainees.

Background

A considerable number of BE/E School trainees fail due to deficiencies in basic mathematics. BE/E School instructors have informally tutored students who have been identified as potential failures prior to beginning their electronics study, and those who have experienced difficulties with requisite mathematics skills early in the curriculum. This tutoring has been conducted as instructors have been available and on a basis of one teacher to a group of six to ten students. Student problems with mathematics stem from background deficiencies, poor student selection procedures, and lack of student motivation and/or proper attitudes.

Approach

Two learning tasks which provide the most difficulty for students were selected and instructionally programmed for the PLATO IV system. Drill and practice routines for the two tasks were prepared in three methods. Two games were designed which utilized PLATO IV display capabilities, along with a conventional problem presentation followed by answer feedback routine. A group of students was assigned to each of the counterbalanced order of the independent tasks. Within each group, students received one of the six possible combinations of the three methods (conventional and two games).

Findings and Conclusions

No significant differences in performance or training time measures were found between the three training methods. Questionnaire data indicated that students who experienced both game mathematics practice and conventional practice definitely preferred game practice. They did not become bored or satiated with game drill, and expressed a definite preference for one game over the other. The best predictor of mathematics proficiency in this study was the Arithmetic Reasoning Test (ARI) score. Other student background measures were not as predictive.

Effectiveness of game displays is dependent on reliable PLATO IV system operation. It was observed that the effectiveness of using games as an instruction technique suffered more than that of the conventional method when hardware and software operations were unstable. Due to favorable student reaction to game practice, further development and evaluation of instructional games are warranted.

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INTRODUCTION

The PLATO (Programmed Logic for Automatic Teaching Operations) IV computer-based education system has flexible graphic display capabilities which make student instruction highly attractive. A high-speed computer linked with a graphic pictorial display terminal can provide new stimuli to the student. Animated graphics can be designed to provide interesting variety for the student, while the system stores and records student responses and response latencies for later retrieval. The present study explored the use of games designed for the PLATO IV system in teaching mathematics skills to students required to complete Basic Electricity/Electronics (BE/E) School at the Naval Training Center, San Diego, California.

In terms of teaching methods, Suppes, Jerman, and Brian's (1968) program started a new era of concern with individualized teaching. They identified variables for analyzing and predicting the response and latency performance of children solving arithmetical problems. This project and others, such as Individually Prescribed Instruction (IPI) in Pittsburgh and Westinghouse Learning Corporation's Project PLAN, have all used computers to maximize individualized instruction. More recently, Slough, Ellis, and Lahey (1972) have demonstrated training time savings of 30% to 60% could be achieved using computer-assisted instruction (CAI) branching techniques rather than fixed sequence strategy.

Coleman (1961) has suggested that schools substitute intergroup competition for interpersonal competition in the classroom. He feels that this change would require the creation of new forms of competition. Although games have enjoyed popularity in business management training, they haven't been fully investigated as training aids in other settings. Coleman thinks motivation may be sharply altered by restructuring rewards, and by using informal group rewards to reinforce training objectives rather than impede them.

A question which arises is why games are intrinsically motivating. According to Woodworth (1958), the tendency to deal with the environment is basic in motivation. He states that direction of activity toward the environment is "the fundamental tendency of animal and human behavior and that it is the all pervasive primary motivation of behavior." In the learning environment, White's (1959) theory of effectance motivation posits that the student will be motivated to respond so as to make changes in what he is watching. It follows that a student will be more highly motivated by the change-providing situations afforded by game participation than by a conventional learning environment.

Lutz (1973) and Lutz and Anderson (1973) have studied the effect of what they call multimode knowledge of results (KR) in teaching letter-sound associations to elementary school children. Simple knowledge of results consisted of only a positive audio message, whereas multimode KR was an audio message plus a change in the visual stimulus following a correct answer. In terms of the percent of time students were distracted, the multimode KR was significantly more effective. In other words, Lutz found that the dynamic, changing pictorial response feedback provided by PLATO IV displays caused students to attend to their learning tasks a greater percentage of the time.

The theorized motivational benefits of competitive activity and the results of multimode KR have led to the present study, which utilizes pictorial game presentations to provide mathematics drill and practice sessions. In the game versions, students' responses to practice problems resulted in both continuous and accumulative changes in their visual displays. This was accomplished by comparing two game presentations to the conventional practice of providing straight problems followed by feedback presentations to determine whether the game form of drill and practice would prove superior. Conventional mathematics practice was compared with ongoing game competition between the student and the PLATO IV system.

METHOD

Design

Conventional practice was compared with two types of games, tug-of-war and speedway. A counterbalanced design was used to investigate the effects of the three training methods on performance. Two tasks--powers-of-ten and formula solving--provided the subject matter for the study. Subjects were split into two groups to control the sequence in which the tasks were done. Within each group, each student was given a different training method for each of the two games (Table 1). Thus, in Group II, the "CS" students used conventional practice for formula solving and speedway for powers-of-ten. Random assignment of 48 students to the six combinations of training methods yielded four students per combination in each counterbalanced task group.

Subjects

All 48 students were Navy trainees in the Basic Electricity/Electronics (BE/E) School, Service School Command, Naval Training Center, San Diego, California. Students were selected who needed strengthening of mathematics skills. Participation in the study was voluntary. Students utilized were those who had not begun the individualized BE/E curriculum or who had started the beginning materials and were experiencing difficulty solving problems.

Equipment

The two learning tasks were presented on PLATO IV, an instructional time-sharing system headquartered at the University of Illinois (UI), Urbana, Illinois. The present study was conducted on 12 student terminals located at the Naval Training Center, San Diego, California.

TABLE 1

Assignment of Students

	Task	
	Powers-of-ten	Formula Solving
Group I N=24	Method Combinations Used In Each Group*	
	1. CS 2. CT 3. SC	4. ST 5. TC 6. TS
Group II N=24	Task	
	Formula Solving	Powers-of-ten

*C = Conventional Practice
T = Tug-of-war Game
S = Speedway Game

Operation of the PLATO IV system is controlled by a large CDC 6400 computer system located at UI. Communication with terminals in San Diego is via voice grade telephone lines. Three lines are used, each of which are terminated in San Diego with a multiplexer. Each multiplexer services four terminals. The average time for a student entry to be sent to the computer, processed, and returned and displayed on the terminal in San Diego is 212 milliseconds.

The PLATO IV student terminal (Figure 1) is an interactive computer graphics terminal with an 8.5-square-inch plasma display panel. The terminal permanently stores information on the display screen which does not require refreshing by the computer. Characters appear on the screen at a speed of 180 characters per second with a capacity of 2,048 characters. Fine drawing speed is in excess of 600 inches per second. There are 252 characters available, 126 of which are alterable via the computer program. A random-access slide projector within each terminal is used for rear projection of static information on the display screen. Student terminals accommodate random-access audio response units and have additional input-output channels for controlling auxiliary equipment. Stifle (1970 and 1971) provides a more detailed PLATO IV system and terminal description.

Courseware

Two learning tasks were used in this study--powers-of-ten and formula solving. Powers-of-ten involves learning how to add, subtract, multiply, divide, square, and extract square roots of numbers expressed as powers-of-ten. Formula solving requires that the student transpose formulas such

Fig. 1. PLATO IV Student Terminal

as Ohm's Law ($E = IR$) or reactance formulas (e.g., $X_L = 2\pi FL$) correctly to solve for an unknown value. The skills required are direct substitution into formulas, correct placement of the decimal point, and identification and correct use of metric prefixes in problem solving.

A set of rules for reaching the objectives of both tasks was made available to the students (Figure 2). The rules for both tasks consisted of explanatory information presented in fixed sequence with examples of problem types to be solved during practice sessions. The course design required students to complete practice sessions for both tasks. Review of rules was optional before the practice session and between practice rounds (see Figure 2).

The three training methods employed in the task practice sessions were conventional, tug-of-war game, and speedway game practice. Within each task, identical problems were presented to students in each of the three methods. The amount of answer feedback was the same for each of the three methods.

In conventional practice, the problem was presented to the student, he responded via the keyboard, and answer feedback appeared. The only screen display the student saw was the problem, a cursor where his answer was accepted, and a correct or incorrect evaluation after he entered an answer.

Tug-of-war game practice consisted of the same problem presentation as conventional practice, in addition to a display showing a tug-of-war game (Figure 3). The student competed against PLATO (his opponent) and

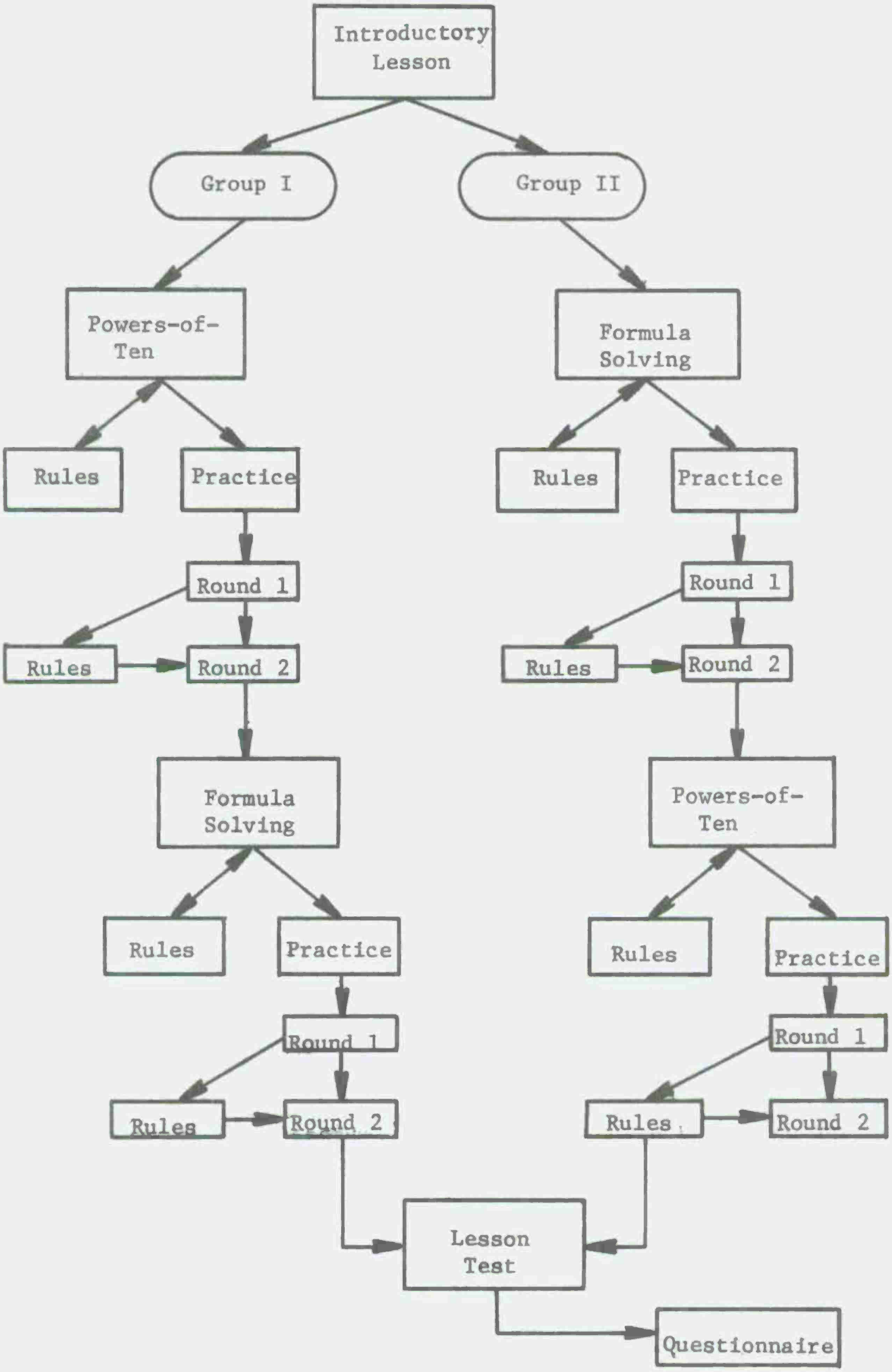

Fig. 2. Review Mathematics Lesson Design

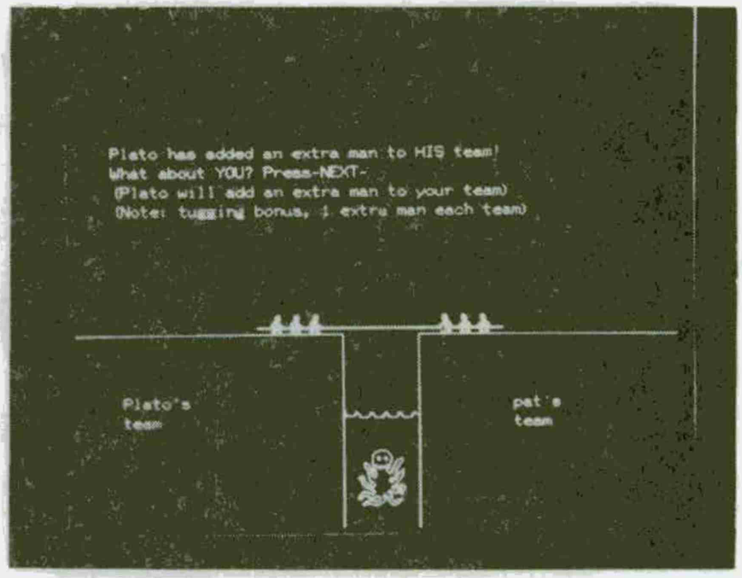

Fig. 3. Tug-of-war Game Display

received a man for his team when answering correctly. If the student answered incorrectly, PLATO added a man to his side of the tug-of-war. At the end of Round 1 (five problems), the team with the most men pulled the other team into the ocean to be consumed by an octopus appearing on the game display. At the end of two rounds (ten problems), there was a tug-of-war between the men accumulated over both rounds by the student and his opponent, PLATO.

The speedway game was also a competition between the student and the system. In this game, two race cars were displayed on the screen, one identified as the student and the other as PLATO (Figure 4). For each of the problems solved correctly, the student's car advanced a predetermined distance towards the finish line. An incorrect answer moved PLATO's car ahead. Again, after five problems or Round 1, whichever car is ahead, PLATO's or the student's, races to the finish line to leave his opponent in the dust! At the end of Round 2 (ten problems), both cars race. The result is determined by their cummulative score over Rounds 1 and 2.

Evaluation Measures

A lesson test was used to evaluate student proficiency in the two tasks--powers-of-ten and formula solving. The test was 16 multiple-choice items, with eight devoted to each task. The purpose of this test was to measure the relative effectiveness of the three training methods as reflected by student achievement scores.

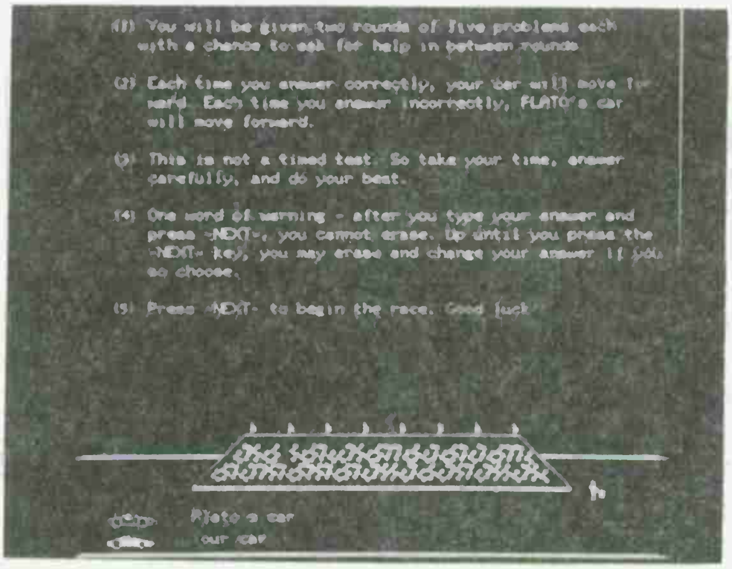

Fig. 4. Speedway Game Display

Student background measures were also obtained. These included his scores on the General Intelligence Test (GCT), Mathematics Reasoning Test (ARI), Mechanical Aptitude Test (MECH), Electronics Aptitude Test (ETST), and the 20-item math test taken prior to entering BE/E School.

Students completed questionnaires designed to assess their attitudes about the training methods, the PLATO system, and the learning environment they experienced.

Procedure

After the general nature of the experiment was explained to the students, they were randomly assigned identification numbers. These numbers determined each student's task group and training method order. Prior to beginning the lesson, students took a short introductory lesson which explained the use of the terminal keyboard and provided some practice. Students were instructed not to collaborate and to work at their own pace.

After completing both tasks and the lesson test, the students received their test scores and on-line corrective feedback. Then the students were given a questionnaire to complete. This concluded the experimental session.

RESULTS

Performance Measures

Lesson Test. Mean performance measures are summarized in Table 2. A multivariate (variance and covariance) analysis (Biomedical Computer

TABLE 2

Mean Performance

Performance Measures	Method	Powers-of-ten 1st* (Group 1)	Powers-of-ten 2nd (Group 2)	Formula Solving 1st (Group 2)	Formula Solving 2nd (Group 1)
Test Score (%)	Conventional	83.3	81.2	46.7	47.5
	Speedway	65.1	75.1	57.3	42.2
	Tug-of-war	84.5	76.8	55.6	53.0
Lesson Time (min)	Conventional	25.1	20.5	19.8	24.2
	Speedway	30.7	17.0	29.3	26.1
	Tug-of-war	28.7	27.4	24.7	27.6
Lesson Score (%)	Conventional	35.0	30.1	50.9	52.4
	Speedway	37.3	40.7	56.2	44.1
	Tug-of-war	29.2	28.4	46.1	58.4

*Powers-of-ten training given before formula solving training

Program Series, UCLA, BMD12V) was completed on test scores for both tasks (Table 3). The largest difference between methods is seen in the powers-of-ten task. However, it was not significant. The ARI scores contributed the largest difference between students for both tasks ($p < 0.05$).

<u>Lesson Time</u>. Lesson time recorded included practice time spent by students on each of the two tasks. Here, there was a significant difference between groups on the powers-of-ten task. Group I, which did powers-of-ten first, was slower ($p < 0.05$). GCT accounted for the greatest source of covariation between students on the formula-solving task. The BE/E School's math test also accounted for a significant amount of student variation in time required to complete the formula-solving task.

<u>Lesson Scores</u>. Within each task, a record kept of the percentage of correct student responses yielded an overall method or task score (Table 3). A significant interaction between method and group (MxG)

TABLE 3

Analysis of Covariance for Performance Measures

Source	df	F Ratio					
		Test Score		Lesson Time		Lesson Score	
		Pwr-Ten	Fr-Solv	Pwr-Ten	Fr-Solv	Pwr-Ten	Fr-Solv
Method	2	2.24	<1.0	<1.0	1.81	1.19	<1.0
Group	1	<1.0	1.05	4.20*	<1.0	<1.0	<1.0
M x G	2	1.13	<1.0	1.20	<1.0	<1.0	4.34*
Covariates:	5						
GCT	1	<1.0	1.36	<1.0	6.66*	1.17	4.74*
ARI	1	6.39*	5.85*	<1.0	1.19	4.71*	7.59**
MECH	1	1.46	<1.0	<1.0	1.98	2.00	<1.0
ETST	1	<1.0	<1.0	<1.0	<1.0	3.16	1.35
Math Test	1	<1.0	<1.49	<1.69	4.59*	<1.0	1.09
Error Variance	37	246.74	343.28	117.09	67.68	282.95	116.50

*p < 0.05
**p < 0.01

occurred, since Group I students achieved much higher formula-solving scores during speedway game practice. This was a reversal of results of the formula-solving, conventional, and tug-of-war practice sessions, where Group I students scored lower than Group II students. Here again, ARI scores provided the major source of differences between student performance on the formula-solving and powers-of-ten tasks, $p < 0.05$ and $p < 0.01$ respectively. GCT scores covaried significantly with formula-solving performance ($p < 0.05$).

Correlational Analysis

Correlation analyses were performed between the student test scores (GCT, ARI, MECH, ETST, and math test) and student performance measures (Table 4). ARI scores proved to be the best overall predictor of performance and GCT scores were the weakest predictors of test and lesson

TABLE 4

Correlation Between Background Measures and Performance*

Background Measures	Test Score		Lesson Time		Lesson Score	
	Pwr-Ten	Fr-Solv	Pwr-Ten	Fr-Solv	Pwr-Ten	Fr-Solv
GCT General Intelligence Test	0.036	0.079	-0.142	-0.377	0.070	0.015
ARI Math Reasoning Test	0.279	0.557	-0.292	-0.332	0.509	0.578
MECH Mechanical Aptitude	-0.259	0.109	0.062	-0.001	-0.023	0.091
ETST Electronics Aptitude Test	0.055	0.377	-0.175	-0.235	0.383	0.392
Math Test Given to all students entering BE/E School	0.037	0.486	-0.244	-0.387	0.384	0.455

*Correlation coefficients $\geq$ 0.32 are significant at $p < 0.05$.

scores. The BE/E School's math test scores were less efficient for predicting performance than the ARI scores.

Student Attitude Questionnaire

As can be seen from the questionnaire responses (Table 5), students' reactions to game practice were very positive. Of the students who experienced both games, those in method combinations 4 and 6 (Table 1) expressed a definite preference for tug-of-war game practice over speedway game practice. Besides the game aspect of practice, students were aware of what the training objectives were and felt that the material was presented effectively. Pearson r's calculated between ratings of Questions 3 and 4 (assigning "1" to 0% and poor, and "5" to 100% and outstanding) and lesson test scores yielded 0.226 and 0.270 respectively.

TABLE 5

Responses to Evaluation Questionnaire

Question	Response Frequency				
1. Which type of problem solving did/would you prefer? N = 48	Regular Practice 14		Game Practice 34 $p<0.006$ (Z score, 2-tailed)		
2. If you played both tug-of-war and speedway games, which did you prefer? (Applicable to Groups 4 & 6) N = 16	Speedway 2		Tug-of-war 14 $p<0.003$ (Z score, 2-tailed test)		
3. In future lessons, what part of problem-solving practice would you like to be in game form? N = 48	4 0-10% $X^2=3.6$ $p<0.10$	7 25% 0.9	15 50% 2.5	12 75% 0.4	10 100% 0
4. Rate the instructional effectiveness of the training materials. N = 42	1 Poor $X^2=6.50$ $p<0.025$	4 Fair 2.3	12 Average 1.54	15 Above average 5.18 $p<0.025$	10 Outstanding 0.30
5. How well did you understand what you were supposed to learn, (i.e., how clear were the training objectives)? N = 42	2 0% $X^2=4.88$ $p<0.05$	3 25% 3.47 $p<0.10$	12 50% 1.54	15 75% 5.18 $p<0.025$	11 100% 0.80
6. The instructional material was presented too quickly (needed smaller steps). N = 42	9 Never $X^2=0.04$	10 Occasionally 0.30	12 Frequently 1.54	8 Usually 0.01	3 Always 3.47 $p<0.10$
7. Too much material was presented at one time on the screen (screen was crowded). N = 42	18 Never $X^2=10.97$ $p<0.005$	16 Occasionally 6.88 $p<0.01$	7 Frequently 0.23	0 Usually 0	1 Always 6.50 $p<0.025$
8. Arrangement (spacing, format, distribution, etc.) of materials on the screen was excellent. N = 42	6 Never $X^2=0.69$	2 Occasionally 4.88 $p<0.05$	3 Frequently 3.47 $p<0.10$	10 Usually 0.30	21 Always 18.90 $p<0.005$

PLATO System Operation

Table 6 summarizes the experiences of students during this study. Two major types of transmission problems occurred which interrupted student progress at various terminals.

The first problem occurred when transmission of data between the student terminal in San Diego and the computer in Urbana, Illinois became "garbled" and the student's display was distorted. This resulted in (1) eliminating the tug-of-war or speedway display entirely causing the game score to register inaccurately, (2) "clobbering" the display on the student's screen so that it was not readable, or (3) stalling the student's terminal so that additional keyboard entries would not advance the lesson program. These failures were limited usually to one or two terminals at one time. Usually the experiment proctors were able to restore screen displays by entering certain commands at the affected student's keyboard.

The second major operational problem was the shutdown of total system operation without the cognizance of study proctors. This resulted in the loss of student performance data described previously. In these cases, the affected students were eliminated from the study and their identification numbers were returned to the pool and drawn by replacement students. In addition, the performance data recording program malfunctioned twice due to overflowing available storage space and program switching errors. The latter conditions were rectified at the San Diego experimental site.

Student data recovered and the overall operational experience during the study is summarized in Table 6. The experimenters took precautions to optimize system operation at all times. Questionable student records were discarded and replaced by those generated by students in later trials.

DISCUSSION AND CONCLUSIONS

The results indicated that game practice is not superior to conventional practice and that there is no significant difference between the two different game presentations. Whatever motivational benefits may be attributed to game practice in terms of test score, lesson time, and lesson score was not apparent with these experimental tasks. The alleged benefits of instrinsic motivation and the dynamic, changing pictorial response feedback characteristics of the tug-of-war and speedway games did not manifest themselves in this study as measured by the selected dependent measures. It may be that a measure such as distraction time or time attending to the visual display (as in the Lutz (1973) study) would have pointed to differences between methods.

Student evaluation of game practice was excellent. As can be seen from Table 5, there was a definite preference for game practice (Question 1) and for tug-of-war over speedway (Question 2). It is likely that the tug-of-war game held more suspense for students and had more climactic humor than the speedway game. On the questionnaire, students were

TABLE 6

PLATO System Operation

Student Trial No.	Number of Student Participants	Frequency of Line Errors	Frequency of Display Restorations	System Interruptions	Student Records Recovered/Number of Students	Reason for Records Loss
1	4	Some	None	2	27	System Interruption
2	5	Many	Frequent	0	5/5	
3	11	Some	Some	1	6/11	System Interruption
4	5	Some	None	0	4/5	Performance Program Error
5	9	Some	None	1	5/9	Performance Program Error
6	11	Some	Some	1	11/11	
7	6	Some	None	1 (preplanned)	6/6	
8	12	Some	Some	1	12/12	

encouraged to make general comments. Students did not feel that the games were too simple, or that they had been insulted by being taught "down to" with game practice. This was a concern in the selection and development of the games. The author's intent was to use displays that were interesting and that did not have game rules that were more complicated than the subject matter itself. Apparently this objective was met.

Answers to Questions 3 and 4 were not appreciably biased by reporting performance scores to the students before they completed the questionnaire. This was indicated by the low correlations of 0.226 and 0.270 between total lesson score and ratings on these questions. Answers to Question 5 showed that most of the students understood what the lesson objectives were. Thirty-eight responses out of 42 ranged from "understood" (50%) to "completely understood" (100%).

In contrast, answers to Question 6 indicated that the instructional material was presented too quickly and that most students desired smaller instructional steps. As a result, the general rules available were reviewed frequently. During the study, Group I students utilized the rules 71 times and Group II students 56 times. Apparently the amount and arrangement of material on the display screen was satisfactory and independent of instructional step size (Questions 7 and 8).

BE/E School's math test did not predict performance on the review mathematics lessons in this study as well as the traditional ARI test scores. Interestingly, mechanical aptitude scores correlated negatively with powers-of-ten test and lesson performance scores (Table 4). All background measures predict formula-solving performance better than powers-of-ten test scores, with GCT correlating less with all performance measures than the other background tests.

Undoubtedly, game practice suffered more than the conventional practice from transmission problems between the central computer and student terminals. As can be seen from Table 6, during Student Trial Numbers 2, 3, 6, and 3, students' displays had to be restored so that the students could continue their progress. This type of disruption as well as total system shutdowns affected game practice more than conventional because the cummulative scoring and display continuity of the game was interrupted. Unfortunately, it was not possible to accurately record at what point in the lesson the interruption occurred since the student often did not realize his presentation was in error until some time later. However, disruptions did not deteriorate student attitudes, as measured by the evaluation questionnaire (Table 5), or as reflected by comments to study proctors. However, a more stable system operation undoubtedly would enhance the effectiveness of instructional games.

Due to favorable student reaction to game practice, further development and evaluation of instructional games are warranted. Application of games to different tasks of longer duration might be revealing. Competition between students rather than between a student and a CAI system may prove more effective. Game complexity should be systematically varied and evaluated. Monitoring physiological indices of student performance may provide further insight into the effect of the dynamic visual stimuli characteristic of computer-based instructional games.

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