CALIFORNIA STATE UNIVERSITY, NORTHRIDGE

FLOWCHARTS USED FOR PROCEDURAL INSTRUCTIONS

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by

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ABSTRACT

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An experimental study was conducted to evaluate two factors in the graphic structure of flowcharts used for a problem solving task. The two factors were the directional orientation of the flowchart and the number of alternatives leading from decision boxes. A third factor evaluated was problem complexity.

Sixty-four subjects were randomly assigned to eight experimental groups. Seven groups used variations of binary and multiple alternative flowcharts to solve problems. Binary flowcharts had two alternatives leading from decision boxes while multiple alternative flowcharts had three or four alternatives leading from decision boxes. The flowcharts also varied in directional orientation which

was the direction in which the flowchart led the reader (left-to-right, top-to-bottom, right-to-left, and top-left-right-bottom). The eighth group used prose in paragraphs to solve problems. The subjects were required to solve 15 simple and 15 complex problems using the procedural instructions. The performance measures were the number of incorrect solutions to problems, the time used to view the formats, and the time used to solve problems. Two major conclusions were made: 1) Performance was best when the directional orientation of the flowchart was consistent with reading patterns. The best configurations for the graphic structure are either from left-to-right or from top-to-bottom. 2) The number of alternatives leading from decision boxes had no effect on performance.

INTRODUCTION

This research investigates the use and format of flowcharts to present procedural instructions for a problem solving task.

Written procedural instructions play an important role in presenting complex information to individuals. Flowcharts are an alternative to presenting instructions written in prose and can be used to assist the user in understanding and completing a specific task. Like many job performance aids, the information in the flowchart is organized and recorded in print. The user retrieves the information when needed by reading. A procedural flowchart assists the reader by graphicly displaying information-decision-action sequences, in order, and clearly identifies unacceptable system conditions. Required decisions are reduced to a minimum, and those that are unavoidable can be reduced to a simple yes/no, binary, form (Rogers, 1963).

There are numerous possibilities for the design of the flowchart's graphic structure and all designs were not considered within the scope of this study. For example, this research does not consider operational sequence diagrams which are often used to represent procedures. Their complexity is increased due to their many shape coded operation boxes and repetitious loops, and further, their purpose is not to assist in task completion.

Two types of flowcharts were investigated in this research. Shown in Figure 1 is the binary flowchart. The binary flowchart is structured in a series of rectangular shapes termed decision boxes. Two alternatives labeled "yes and no" lead from each box. The second type of flowchart is a multiple alternative flowchart which is structured with three or more alternatives leading from each decision box and is shown in Figure 2.

In the flowchart's simplest form, the graphic structures are made up of three components: decision boxes, alternative pathways, and action boxes. Decision boxes are rectangles that contain one or more written questions or sentences about the task to be performed. Alternative pathways are drawn as single lines that lead the reader from one decision box to another decision box or action box. The action box is a rectangle that contains a written statement instructing the reader to perform some behavior or outcome that terminates a particular information-decision-action sequence. A decision box in a binary flowchart contains a single question. The reader considers the answer to the question, chooses a yes/no alternative, and proceeds. The decision box in a multiple alternative flowchart contains two or more sentences, each of which leads to an alternative pathway. The reader chooses the statement that applies to the task and then is led by the corresponding pathway to the next decision or action box.

PROCEDURES FOR TRAVEL

Figure 1. The binary flowchart. (Wright and Reid 1973)

Figure 2. A portion of a multiple alternative flowchart used in this study.

When presenting the same procedural instructions the binary flowchart presents the reader a greater number of decision boxes and fewer alternatives leading from each decision box.

The most widely used format for presenting instructions is prose presented in paragraphs; however, the comprehension of prose is affected by several conditions. For example, a common condition in prose is the use of qualifying clauses. A series of clauses, such as "before permits can be processed, or before the transports can accept cargo, all drivers must report to the scheduling desk" requires the reader to consider every contingency (Davies, 1970). In many situations the reader must sort through the sequence of clauses and determine which clauses apply to the task at hand.

Another example of a condition that affects the comprehension of prose is the use of words that have negative connotations, such as less, worse, and shorter. Using words with negative connotations can result in less accuracy and increased performance times on problem solving tasks (Clark 1969, Jones 1966, Wright and Barnard 1975). Moreover, sentences written in passive voice ("the route schedule is picked up by the driver") rather than the active voice ("the driver picks up the route schedule") also reduces comprehension (Broadbent 1977). In addition, the reader, unknowingly in recall, may transform a sen-

tence written in passive voice into active voice even though this change may alter the meaning of the sentence. Finally, the use of pronouns in a sentence can often make the sentence ambiguous. The reader will often refer a pronoun to the first noun in a sentence, rather than to the noun that immediately preceded the pronoun (Broadbent 1973). For instance the reader would refer "it" to "drive chain" rather than to "sprocket" in the following sentence; "the drive chain is connected to the sprocket and it turns the wheel."

There are several alternatives to prose including the display of instructions in short sentences, matrix tables, and flowcharts. Research has primarily focused on the flowchart for three reasons. First, the graphics of the flowchart reduce the number of words and the complexity for the prose used in the instructions. Second, the flowchart can display a large number of contingencies in a simple format, and third, the reader can easily distinguish between relevant and irrelevant information.

Wright and Reid (1973) evaluated the effectiveness of prose presented in paragraphs, short sentences, a matrix table, and a binary flowchart in conveying procedural instructions. The task required groups to solve 48 problems using one of the instructional formats. The formats involved fictitious space travel, where in subjects made decisions about the cost, time, and distance of travel.

The dependent measures were the number of incorrect solutions to each problem and the amount of time to solve each problem. The between group's experiment was conducted in three phases. The method of presenting the formats varied in each phase. In phase I, each group was allowed to view their instructions throughout the phase and solved 12 simple and 12 difficult problems. When phase II began each group had their instructions removed without warning and solved 12 difficult problems. After the first two phases each group was allowed to study their instructions for five minutes, then the instructions were removed and the group solved another 12 difficult problems.

Wright and Reid (1973) found that in phase I, when each group had continuous access to instructions, there were no significant differences between the four formats when subjects worked on simple problems. When subjects worked on difficult problems, (problems each involving all three - cost, time, and distance details and with one or two irrelevant details) the group using the binary flow-chart made significantly fewer errors than groups using other formats. The group using the table format was the only group to use significantly less time to solve problems than the group using the flowchart. In phase II, during which subjects worked from memory, the average error rate rose from 36 percent in phase I to 70 percent in phase II with no significant differences for error or the time to

solve each problem. Further, when subjects memorized instructions in phase III the average error rate was reduced to 58 percent, yet there were still no significant differences for error or the time to solve problems between groups.

Wright and Reid (1973) concluded that error was the most important measure and that the binary flowchart improves performance when the instructions are present and when problems are difficult and embedded in miscellaneous details. Apparently the flowchart helps the reader distinguish between the relevant and irrelevant details of the problem. Perhaps the flowchart helped the subjects to structure the problem in addition to leading them to a solution. If this is so, other versions of the flowchart designed to assist the reader in structuring his problem may improve performance. One possibility for other versions might be to place more than one question in a decision box giving the reader more information about the decision.

Another possibility might be to place one or two code words at the top of the decision box that are the subject and/or the object of the question in the decision box. These code words might acquire the meaning of the question in the decision box, reduce the amount of reading for the subject on subsequent trials, or might allow irrelevant information to be skipped.

In an extension of the previous study, Blaiwes (1974) examined the effectiveness of procedural instructions presented in short sentences and two binary flowchart formats. The two flowcharts were identical in that both flowcharts contained two questions in most decision boxes. The flowcharts differed in that one contained code words in the top of each decision box, and the other did not.

The task required subjects to solve 30 problems in each of the two test sessions. Prior to the first sessions subjects were required to memorize and then to recall, without error, one of the instructions. In a between groups design, each group worked without viewing the instructional format in the first session. During the second session, groups could view the instructions they had memorized prior to the first session. The dependent measures were the number of incorrect solutions to problems, the time to begin a solution, and the number of times the subject referred back to (viewed) the instructions.

Blaiwes (1974) found, that after averaging the data from both sessions, the group using the flowchart with code words made significantly fewer errors and referrals than did the groups using the flowchart without code words or the short sentences. Furthermore, the group using the flowchart without code words took significantly less time to begin a solution than did the groups using the flowchart

with code words or short sentences.

Blaiwes (1974) concluded that when memory was required, as in the first session, flowcharts are no better than short sentences. The flowchart, on the other hand, was systematically superior to the short sentences when instructions were viewed throughout the task. The decrease in error and referrals when using the coded flowchart indicates that code words served as aids in structuring the problem for the subject. Code words may have served as aids to retrieval of the information or in restructuring the flowchart and thus reduced referrals. Moreover, the codes may have acquired the meaning of the questions in the decision boxes resulting in a more rapid processing of the sequence of contingencies. It was surprising that code words did not decrease the time to initiate the solution since code words might be expected to reduce the amount of the subject's reading and thus effect time. Possibly the subject needs a certain amount of information from the instructions to begin a solution.

The flowchart without code words was not significantly different from short sentences on the two measures, errors and referrals. This may have been due to the multiple questions in the decision boxes. The amount of information the subject must read may make the task as difficult as when a subject reads short sentences. Adding code words to the flowchart may have been necessary to make processing

two questions less difficult. Since short sentences with code words were not compared to the flowchart it is unclear whether or not short sentences would also have benefited from the addition of code words.

In an applied study by Kammann (1975), a one page multiple alternative and a binary flowchart were compared to an existing 16 page telephone directory. The formats were evaluated for their effectiveness in conveying procedural instructions. The task required subjects to solve 16 problems involving the basic uses of a telephone system. Subjects were three groups of engineers and scientists and three groups of housewives. In a between groups design each of the groups used one of the instructions. The dependent measures were the number of incorrect solutions to problems and the total time to solve the 16 problems.

The two flowcharts were noticeably different in several respects. These two flowcharts were not only different in the number of alternatives leading from decision boxes but also differed in the directions in which the reader was led while reading. The binary flowchart began at the top of the page in a series of decision boxes leading, via alternative pathways, to action boxes located on the right, left, and bottom margins of the page. The multiple alternatives flowchart, on the other hand, began on the left margin of the page and ended with action boxes on the right margin of the page. The directional orienta-

tion of a flowchart is determined by its position on the page, where it begins and where the action boxes are located. For example, Kammann's (1975) multiple alternative flow chart had a horizontal, left to right, directional orientation leading the reader from left to right. His binary flowchart, on the other hand, had a vertical, downward, left, and right directional orientation leading the reader downward to the left and to the right. Finally, the binary flowchart contained 51 percent fewer words than the multiple alternative flowchart.

Kammann's (1975) major findings were: (a) there were significantly fewer errors and less time involved in solving problems when flowcharts were used as opposed to the 16 page directory; (b) the housewives using the multiple alternative flowchart required significantly less time and made significantly fewer errors than did housewives using the binary flowchart; (c) there were no differences in performance between scientists and engineers when using flowcharts.

While the main findings in Kammann's (1975) research was that both flowcharts were superior to prose instructions the results are difficult to interpret. The study was not designed to isolate the critical factors which contribute to the flowchart effect. It might be argued that differences between the prose and flowcharts were due to the 16 page length of the prose telephone directory.

Engineers and scientists may have used both flowcharts equally well due to previous exposure to flowcharts they may have encountered in technical literature. Finally, it is difficult to determine whether housewives performed better using the multiple alternative flowchart due to the increased number of alternatives leading from decision boxes or due to the direction in which the reader was led. As Lincoln and Averbach (1956) found, the scanning patterns that people use are highly related to previously learned reading habits. It may be inferred from this study that a left to right directional orientation improved subject performance.

Statement of the Problem

The present study was designed to evaluate various factors in the graphic design of the flowcharts on subject performance during a problem solving task. Like the previous studies by Blaiwes (1974), Kammann (1975), and Wright and Reid (1973), the task required subjects to use one of the flowcharts or prose formats to solve problems. The previous research, however, was not designed to separate the effects of the directions in which the flowchart leads the reader and the number of alternatives leading from decision boxes on subject performance.

In the present experiment eight independent groups used procedural instructions presented as prose, written in

paragraphs, or flowcharts. To test the effects of the number of alternatives leading from decision boxes, the flowcharts were either binary or multiple alternative. To test the effects of directional orientation, the flowcharts were presented in four variations of direction. Thirty problems were presented; fifteen were simple while fifteen were complex.

Three dependent measures were examined: the number of incorrect problem solutions (ERROR); the number of seconds used to view the instructions (VIEWTIME); and the number of seconds used to solve a problem (SOLTIME).

Kammann (1975) found that people performed best when using a multiple alternative flowchart that led the reader from left-to-right. Kammann (1975) however, did not systematically vary the number of alternatives or the directional orientation of the flowchart. Therefore, to examine the effects of direction and alternatives, both factors were systematically varied in this experiment. It was hypothesized that both factors would have a significant effect based on Kammann's (1975) findings. Moreover, based on Kammann's findings, it was hypothesized that groups using the multiple alternative flowcharts would make fewer errors, use less time to view the format, and use less time to solve problems than groups using binary flowcharts. Furthermore, based on Lincoln and Averbach's (1956) findings, it was hypothesized that groups using the flowcharts

with the left-to-right directional orientation would also perform with fewer errors, less time to view the format, and less time to solve problems than groups using flowcharts with other directional orientations.

Two levels of problem complexity were used in this experiment. Since simple and complex problems were found to be significantly different based on pretesting, it was hypothesized that problem complexity would have a significant effect. Moreover, since complex problems are more likely to have a greater effect on performance than simple problems, it was hypothesized that problem complexity would interact with the number of alternatives and the directional orientation of the flowchart. Thus, complex problems were more likely to have a greater effect on the performance than simple problems for flowcharts that were difficult to use.

Method

Subjects. Sixty-four volunteer undergraduate psychology students from California State University, Northridge participated in the experiment. Eight groups each consisted of four female and four male participants. The subjects ranged in age from 17-31 years; mean age was 18.7 years. The volunteers received course credit in introductory psychology courses.

Design. Three factors, the number of alternatives, directional orientation, and problem complexity, were investigated using a $2 \times 3 \times 2$ factorial design. The number of alternatives leading from decision boxes were either binary (two alternatives) or multiple alternatives (three or four alternatives). The directional orientations, or the directions in which the flowchart led the reader, were left-to-right, top-to-bottom, right-to-left. Problem complexity involved simple and complex problems. The number of alternatives and the directional orientation, were between-subjects variables. Problem complexity was a within-subjects variable. The two types of alternatives and the three directions of orientation created six experimental conditions.

Two non-orthogonal conditions were added to the design and were investigated using a 2×8 factorial design. One condition served as a control group in which

subjects used prose written in paragraphs to solve problems. The second condition was a binary flowchart similar to one used in Kammann's (1975) experiment. This flowchart led the reader in directions from top-to-bottom, to the right and to the left. The two non-orthogonal and six orthogonal conditions were presented to eight independent groups.

Three dependent measures were used in the study; incorrect problem solutions, viewing time, and solution time. Solutions to problems (ERROR) were either correct or incorrect for each problem. The number of seconds a subject used to view the format (VIEWTIME) was cumulative for each problem. Subjects could view a format and problem for as long a time and as frequently as they wanted. This was achieved by starting and stopping a cumulative timer each time a subject viewed a format during a problem. The number of seconds a subject used to solve a problem (SOLTIME) was the total time used to solve a problem. SOLTIME included VIEWTIME.

Apparatus. A problem box and view box were built to present problems and procedural instructions, respectively. The apparatus were positioned on a table during the experimental trials and are shown in Figure 3. The problem box contained two 4.5 x 4.5 x 6.5 in (11.25 x 11.25 x 11.25 cm) compartments. Unsolved problems were stored in the left-hand compartments while solved problems were stored in the

Figure 3. The apparatus used in this experiment.

right-hand compartment. A single sliding door was positioned so that the door had to be moved over the solved problem compartment in order to remove and begin work on an unsolved problem. The door then had to be moved over the unsolved problem compartment in order to store and end work on a solved problem. Moving and later repositioning the sliding door started and stopped a digital timer activated by a silent magnetic switch. The timer recorded the number of seconds the subject used to solve a problem (SOLTIME). The timer was concealed from the subject behind the problem box.

The view box had a 16 x 14 in (48 x 42 cm) window through which the subjects viewed the procedural instructions. The window was covered with a light blue acetate mylar sheet on the inside of the box. Inside, above and below the window, were 15 watt incandescent light bulbs which were activated by an on-off push button below the window. The procedural instructions were mounted on a large board 3 in (7.5 cm) behind the window. The subject had to push the on-off button to turn on the lights and see the instructions. Pushing and releasing the button started and stopped a cumulative timer that recorded the time the subject used to view the procedural instructions (VIEWTIME). The timer was concealed from the subject behind the view box.

Instructional Formats. The practice and experimental trial procedural instructions and problems are shown in Appendix A. Several criteria were considered in developing the materials. The criteria are:

1. The procedural instructions must have structural components similar to those used in previous research (i.e. decision boxes, action boxes, binary or multiple alternatives).
2. The procedural instructions must express information that can be displayed in binary and multiple alternative flowcharts, and prose written in paragraphs.
3. The prose used in all formats must contain no unnecessary words.
4. All procedural instructions must be displayed on a single surface or page.
5. The problems to be solved must be similar to tasks the subjects are likely to have previously experienced.

Practice trial materials for all groups involved instructions presented in prose and 5 problems about fictitious emergency procedures. All groups used prose in the practice trials rather than flowcharts. The result of this procedure produced conservative differences between groups for the experimental trials. Experimental trial materials involved either the prose or the flowcharts and 30 problems about a fictitious university registration procedure.

There were several structural differences between the flowcharts and the prose used in the experimental trial. For example, 257 words comprised the prose written in

paragraphs while 197 and 137 words comprised the multiple alternative and binary flowcharts respectively. Thus, there were 47 percent fewer words in the binary flowchart and 23 percent fewer words in the multiple alternative flowchart than in the prose written in paragraphs. Further, there were 12 decision boxes and 24 alternatives in the binary flowchart while there were 5 decision boxes and 17 alternatives in the multiple alternative flowchart. Finally, the questions in the decision boxes of the binary flowcharts were simple sentences. The statements in the decision boxes of the multiple alternative flowcharts were often compound sentences.

The directional orientation of each flowchart was varied by using separate one-page flowcharts. The first binary and multiple alternative flowcharts began on the border of the left margin and ended with action boxes on the border of the right margin. The second binary and multiple alternative flowcharts began at the top of the page and ended with action boxes on the bottom of the page. The third binary and multiple alternative flowchart reversed the usual reading directions by beginning on the right border of the margin and ending with action boxes on the left border of the margin. The orthogonal combinations of the three directional orientations and two types of alternatives account for six experimental conditions.

The seventh experimental condition was a binary flowchart with a directional orientation used by Kammann (1974). This flowchart began at the top of the page and ended with action boxes on the left border, right border, and the bottom of the page. The eighth condition was the prose instructions written in paragraphs. The flowcharts and prose described the same procedure; the prose did not contain irrelevant information or unnecessary words. Appendix A includes the flowchart and prose formats.

The 30 problems presented to subjects were pilot tested for difficulty using 10 subjects. Forty problems were used in the pilot study; four problems were discarded as too difficult or too time consuming. Subjects made significantly more errors solving complex problems than simple problems [Sandler's A ($n = 10$) = .201 $p < .05$]. Moreover, subjects used significantly more time solving complex problems than simple problems [Sandler's A ($n = 10$) = .268 $p < .05$].

Simple problems were three sentences containing details that were written in the decision boxes of the flowcharts. Complex problems were three sentences containing details that were written in the decision boxes of the flowcharts and two sentences containing details that were not written in decision boxes and not needed to solve problems. The sentences in both simple and complex problems were listed in random order. Thus, subjects needed

the flowcharts or prose to determine the appropriate sequence of problem sentences in order to solve a problem. In addition, subjects needed the prose and flowcharts to determine which sentences in a complex problem were relevant to the problem.

Procedure. The subjects individually entered a small room and were seated facing the apparatus on the table. The viewbox was positioned to the right of the subject while the storage box was positioned left of the subject (see Figure 3). Table space for writing was open in front of the subject. Verbal instructions were given to the subjects which included an introduction to the experiment, the apparatus, the experimental procedure, and a description of the required responses. The assignment of the subjects to experimental conditions was determined using a random list of numbers. The verbal instructions to subjects are contained in Appendix B.

Subjects were instructed to complete 5 practice trial and 30 experimental trial problems. Subjects were told to work one problem at a time and not to begin a problem until told to do so. The experimenter explained that the procedural instructions, which provided solutions to the problems, were displayed in the viewbox. Moreover, the subjects were told to depress the button on the viewbox only when they wished to read the instructions and to release

the button when they stopped reading the instructions. The subjects were also told they could read the instructions as often as they wished while solving a problem. The experimenter demonstrated the use of the apparatus. Finally, the subjects were trained to follow the procedures during the 5 practice trials and then allowed to begin the 30 experimental trials.

The experimenter recorded the number of seconds displayed on the timers onto a data sheet and reset the timers after each problem. The data sheets were concealed from the subject behind the apparatus.

After the subjects finished the experimental trials the subjects were interviewed about their performance in the experiment. The purpose and procedure of the experiment were explained to the subjects and described in a handout debrief sheet.

Results

In the first analysis, a 2 x 3 x 2 mixed multivariate analysis of variance (MANOVA) was performed on the dependent measures ERROR, VIEWTIME, and SOLTIME. In the second analysis, two 1 x 8 mixed MANOVAs were performed on the dependent measures to obtain the error terms used in "post hoc" comparisons of the orthogonal group means with the non-orthogonal group means. The analyses were conducted using SAS (1979) and SPSS (1975) computer programs.

Several assumptions of MANOVA were examined prior to the analysis and are described in Appendix C. The examinations revealed no violations of the assumptions and the analysis continued using an approach described in Himmelfarb (1975).

Analysis I

A 2 x 3 x 2 mixed MANOVA was performed to determine the effect of the independent variables on the combined dependent measures. The independent variables were the number of alternatives leading from decision boxes, the direction in which the flowchart led the reader, and simple and complex problems. Only six orthogonal flowchart conditions were tested in this overall analysis. The analysis using Wilk's criterion is shown in Table 1.

Three significant effects were found in the overall analysis. First, the directional orientation of the flow-

Table 1

Overall Tests of Analysis I Using Wilk's Criterion

Effect	df	F	Significance	Strength of Association
Directional Orientation	6/80	5.00	0.000	.21
Number of Alternatives	3/40	0.26	0.851	
Problem Complexity	3/40	38.13	0.000	.55
Direction by Alternatives	6/80	0.53	0.781	
Directions by Problems	6/80	3.61	0.003	.15
Alternatives by Problems	3/40	0.72	0.545	
Directions by Alternatives by Problems	6/80	0.57	0.750	

chart was moderately associated with the combined dependent measures (approximate $F_{6,80} = 5.00$; $p < .001$; $n = .21$). Second, problem complexity was strongly associated with the combined dependent measures (approximate $F_{3,40} = 38.13$; $p < .001$; $n = .55$). Third, the directional orientation by problem complexity interaction was weakly associated with the combined dependent measures (approximate $F_{6,80} = 3.61$; $p < .01$; $n = .15$). The number of alternatives leading from decision boxes and the other interactions did not significantly affect the combined dependent measures.

A step-down analysis was performed to analyze the dependent measures individually. Each dependent measure was analyzed, in turn, with the higher priority dependent measures entered as covariates. The highest priority measure was tested in a univariate analysis of variance. The ERROR measure entered the equation first followed by VIEWTIME and SOLTIME. ERROR was given the highest priority because the flowchart loses its utility if it cannot be used accurately. VIEWTIME entered the equation second as it is likely to be sensitive to factors making the reading of a flowchart difficult. SOLTIME was given the lowest priority. An experimentwise error rate of five percent was achieved by the appropriate apportionment of the alpha level.

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The step-down tests and "post hoc" comparisons of group means are discussed for the significant effects found in the overall tests of Analysis I. The step-down tests are shown in Table 2. The unadjusted and adjusted group means and standard deviations are shown in Table 3.

Directional Orientation. The directional orientation of the flowchart was significantly associated with the ERROR measure (step-down $F_{2,42} = 32.69$; $p < .01$; $n = .58$). Moreover, after removing the influence of the ERROR and VIEWTIME measures, directional orientation was significantly associated with the SOLTIME measure (step-down $F_{2,40} = 7.34$; $p < .01$; $n = .19$). Directional orientation, however, did not significantly effect the VIEWTIME measure after removing the influence of the ERROR measure.

Tukey comparisons were conducted on the adjusted marginal means. The groups using the binary and multiple alternative flowcharts were combined for each of the three directions. The Tukey comparisons for the ERROR and SOLTIME measures are shown in Table 4. The comparisons indicated that groups using the flowcharts with the left-to-right ($\bar{M} = 3.51$) and top-to-bottom ($\bar{M} = 4.01$) directional orientations made significantly fewer errors than groups using the flow charts with the right-to-left directional orientations ($\bar{M} = 6.19$). Furthermore, groups using the flowcharts with the left-to-right directional orientations ($\bar{M} = 36.44$) used significantly less SOLTIME

Table 2

Step-down Tests of Analysis I for Directional Orientation, Number of Alternatives, and Problem Complexity

Dependent Variable	Effect	Univariate F	df	Priority	Step-down F	df	Critical F	α
ERROR	Directions	32.69	2/42	1	32.69*	2/42	5.88	.01
	Alternatives	0.81	1/42		0.81	1/42	7.31	.01
	Problems	28.13	1/42		28.13*	1/42	7.31	.01
	D by A	0.58	2/42		0.58	2/42	5.88	.01
	D by P	0.28	2/42		0.28	2/42	5.88	.01
	A by P	0.49	1/42		0.49	1/42	7.31	.01
	D by A by P	0.41	2/42		0.41	2/42	5.88	.01
VIEWTIME	Directions	7.67	2/42	2	0.14	2/41	5.88	.01
	Alternatives	0.02	1/42		0.00	1/41	7.31	.01
	Problems	50.82	1/42		2.32	1/41	7.31	.01
	D by A	0.26	2/42		0.42	2/41	5.88	.01
	D by P	10.86	2/42		9.68*	2/41	5.88	.01
	A by P	0.22	1/42		0.07	1/41	7.31	.01
	D by A by P	0.97	2/42		0.59	2/42	5.88	.01
SOLTIME	Directions	4.80	2/42	3	7.34*	2/40	5.88	.01
	Alternatives	0.02	1/42		0.84	1/40	7.31	.01
	Problems	92.01	1/42		0.23	1/40	7.31	.01
	D by A	1.61	2/42		4.87	2/40	5.88	.01
	D by P	2.23	2/42		0.00	2/40	5.88	.01
	A by P	1.92	1/42		0.84	1/40	7.31	.01
	D by A by P	1.08	2/42		0.45	2/40	5.88	.01

** significant

Table 3

Unadjusted Means, Adjusted Means, and Standard Deviations For Each Condition

ERROR		No Covariates		
<u>Simple Problems</u>	Unadjusted Means	Unadjusted Std. Dev.	Adjusted Means	Adjusted Std. Dev.
Binary Alternatives				
Left to Right	3.25	1.04		
Top to Bottom	3.88	1.96		
Right to Left	5.50	1.85		
Top, Left, Right, Bottom	5.37	1.92		
Multiple Alternatives				
Left to Right	2.63	1.41		
Top to Bottom	3.00	1.69		
Right to Left	5.38	1.68		
Prose	4.75	1.91		
<u>Complex Problems</u>				
Binary Alternatives				
Left to Right	4.50	1.41		
Top to Bottom	4.75	1.67		
Right to Left	6.62	2.67		
Top, Left, Right, Bottom	6.63	1.92		
Multiple Alternatives				
Left to Right	3.63	1.60		
Top to Bottom	4.38	1.51		
Right to Left	7.25	1.83		
Prose	6.63	1.19		

Table 3 continued

VIEWTIME		With ERROR as a Covariate		
<u>Simple Problems</u>	Unadjusted Means	Unadjusted Std. Dev.	Adjusted Means	Adjusted Std. Dev.
Binary Alternatives				
Left to Right	10.13	3.56	12.24	1.51
Top to Bottom	12.25	3.92	13.56	1.41
Right to Left	13.88	5.41	13.07	1.37
Top, Left, Right, Bottom	15.63	3.46	14.98	1.36
Multiple Alternatives				
Left to Right	9.38	4.57	12.30	1.65
Top to Bottom	11.50	2.13	13.94	1.56
Right to Left	13.38	3.25	12.73	1.36
Prose	31.25	4.71	31.42	1.35
<u>Complex Problems</u>				
Binary Alternatives				
Left to Right	15.25	5.39	15.75	1.36
Top to Bottom	13.63	4.60	13.80	1.34
Right to Left	24.00	14.42	21.74	1.54
Top, Left, Right, Bottom	22.25	6.07	18.99	1.53
Multiple Alternatives				
Left to Right	12.00	4.66	13.63	1.45
Top to Bottom	15.25	4.17	15.91	1.36
Right to Left	26.00	10.92	22.93	1.67
Prose	42.75	5.15	40.49	1.53

Table 3 continued

SOLTIME		With ERROR and VIEWTIME as Covariates		
<u>Simple Problems</u>	Unadjusted Means	Unadjusted Std. Dev.	Adjusted Means	Adjusted Std. Dev.
Binary Alternatives				
Left to Right	29.25	9.75	33.60	2.66
Top to Bottom	33.75	8.68	36.95	2.40
Right to Left	34.75	4.96	37.28	2.38
Top, Left, Right, Bottom	37.88	10.20	39.35	2.23
Multiple Alternatives				
Left to Right	25.13	8.13	29.81	2.85
Top to Bottom	34.50	6.82	37.99	2.60
Right to Left	33.63	6.86	36.43	2.40
Prose	44.50	4.04	35.37	3.54
<u>Complex Problems</u>				
Binary Alternatives				
Left to Right	41.13	13.51	42.67	2.18
Top to Bottom	39.63	13.76	42.17	2.28
Right to Left	50.25	7.91	46.99	2.53
Top, Left, Right, Bottom	53.38	13.36	51.74	2.42
Multiple Alternatives				
Left to Right	36.38	14.16	39.68	2.45
Top to Bottom	49.38	11.41	50.89	2.18
Right to Left	52.00	10.69	47.67	2.83
Prose	60.63	7.80	46.27	5.33

Table 4

The Tukey Comparisons of Marginal Means For Directional
Orientation in Analysis I.

ERROR (unadjusted means, C.D.* = 1.27)

Left-to-right vs. Top-to-bottom

$$3.51 - 4.01 = 0.50 \quad \underline{p} > .05$$

Left-to-right vs. Right-to-left

$$3.51 - 6.19 = 2.68 \quad \underline{p} < .05^{**}$$

Top-to-bottom vs. Right-to-left

$$4.01 - 6.19 = 2.18 \quad \underline{p} < .05^{**}$$

SOLTIME (adjusted means, C.D.* = 3.33)

Left-to-right vs. Top-to-bottom

$$36.44 - 42.00 = 5.56 \quad \underline{p} < .05^{**}$$

Left-to-right vs. Right-to-left

$$36.44 - 42.09 = 5.65 \quad \underline{p} < .05^{**}$$

Top-to-bottom vs. Right-to-left

$$42.00 - 42.09 = 0.09 \quad \underline{p} > .05$$

* Critical Difference

** Significant

than the groups using the flowcharts with the top-to-bottom ($M = 42.00$) and right-to-left ($M = 42.09$) directional orientations.

Problem Complexity. Simple and Complex problems were significantly associated with the ERROR measure (step-down $F_{1,42} = 28.13$; $p < .01$; $n = 28$). The marginal means for the simple and complex problems are shown in Table 5. Inspection of the adjusted marginal means for ERROR showed that as expected groups solving simple problems ($M = 3.49$) made significantly fewer errors than groups solving complex problems ($M = 5.19$). Problem complexity, however, did not significantly affect the VIEWTIME or SOLTIME measures after the effects of higher priority measures were removed.

Directional Orientation Problem Complexity

Interaction. The interaction of directional orientation and problem complexity was significantly associated with only the VIEWTIME measure (step-down $F_{2,41} = 9.68$; $p < .01$; $n = .22$). This interaction is plotted in Figure 4 using the adjusted group means. There were no significant differences among groups for the VIEWTIME measure when the groups solved simple problems. The Tukey comparisons (shown in Table 6) indicated that groups using the left-to-right ($M = 14.67$) and top-to-bottom ($M = 14.85$) flowcharts required significantly less time to view the format when solving complex problems than the groups using

Table 5

The Tukey Comparisons of Marginal Means For Simple and Complex Problems in Analysis I

Dependent Measures	Simple Problems	Complex Problems
ERROR, unadjusted	3.94*	5.19*
VIEWTIME, adjusted	35.34	45.01
SOLTIME, adjusted	12.97	17.29

* Significantly different, $p < .01$.

Figure 4. The VIEWTIME groups used to solve simple and complex problems for Analysis I.

Table 6

The Tukey Comparison of Adjusted Cell Means For The
Directional Orientation by Problem Complexity
Interaction

Simple Problems (C.D.* = 3.79)

Left-to-right vs. Top-to-bottom

$$12.27 - 13.75 = 1.48 \quad \underline{p} > .05$$

Left-to-right vs. Right-to-left

$$12.27 - 12.90 = 0.63 \quad \underline{p} > .05$$

Top-to-bottom vs. Right-to-left

$$13.75 - 12.90 = 0.85 \quad \underline{p} > .05$$

Complex Problems

Left-to-right vs. Top-to-bottom

$$14.69 - 14.85 = 0.16 \quad \underline{p} > .05$$

Left-to-right vs. Right-to-left

$$14.69 - 22.33 = 7.64 \quad \underline{p} < .05^{**}$$

Top-to-bottom vs. Right-to-left

$$14.85 - 22.33 = 7.48 \quad \underline{p} < .05^{**}$$

* Critical Difference

** Significant

the right-to-left flowcharts ($\bar{M} = 22.33$). The directional orientation by problem complexity interaction did not significantly affect the ERROR or SOLTIME measures.

Analysis II. A 2 x 8 mixed MANOVA was performed to provide step-down tests to analyze the dependent measures individually (shown in Table 7). The effect of Format was significantly associated with the ERROR and VIEWTIME measures (step-down F for ERROR, $F_{7,56} = 5.53$; $p < .01$; $n = .11$; step-down F for VIEWTIME, $F_{7,55} = 28.25$; $p < .01$; $n = .48$). The SOLTIME measure was not significantly affected by the format of the instructions.

Two 1 x 8 mixed MANOVAs, one for simple and one for complex problems, were performed to provide the separate error terms used in the Dunnett contrast of orthogonal and non-orthogonal group means. The two analyses included the six orthogonal flowchart formats and non-orthogonal prose and top-left-right-bottom (TLRB) flowchart formats.

The adjusted cell means for the ERROR and VIEWTIME measures were contrasted using the Dunnett test and are shown in Table 8. When groups solved simple problems, the groups using the left-to-right ($\bar{M} = 2.94$) and top-to-bottom ($\bar{M} = 3.44$) flowcharts made significantly fewer errors than the group using the TLRB flowchart. In addition, when groups solved simple problems, all groups using flowcharts (average $\bar{M} = 13.19$) used significantly less time to view the format than the group using the

Table 7

Step-down Tests of Analysis II For Format and Problem Complexity

<u>Dependent Variable</u>	<u>Effect</u>	<u>Univariate F</u>	<u>df</u>	<u>Priority</u>	<u>Step-down F</u>	<u>df</u>	<u>Critical F</u>	<u>α</u>
ERROR	Format	5.53	7/71	1	5.53*	7/56	2.98	.01
	Problem	58.44	1/71		38.44*	1/56	7.08	.01
	F by P	.38	7/71		.38	7/56	2.95	.01
VIEWTIME	Format	19.29	7/71	2	28.25*	7/55	2.95	.01
	Problem	83.21	1/71		3.33	1/55	7.08	.01
	F by P	4.34	7/71		2.48	7/55	2.95	.01
SOLTIME	Format	4.36	7/71	3	1.69	7/54	2.95	.01
	Problem	153.35	1/71		0.07	1/54	7.08	.01
	F by P	1.63	7/71		0.53	7/54	2.95	.01

* Significant

Table 8

The Dunnett Contrast of Group Means For Analysis II

Simple Problems		Complex Problems	
Direction	Means	Direction	Means
ERROR C.D. = 1.85		C.D. = 2.38	
Left-to-Right	2.94* +	Left-to-right	4.06* +
Top-to-bottom	3.44 +	Top-to-bottom	4.56* +
Prose	4.75	Prose	6.63
TLRB	5.37	TLRB	6.63
Right-to-left	5.44	Right-to-left	6.93
VIEWTIME C.D. = 4.26		C.D. = 7.09	
Left-to-right	12.27*	Left-to-right	14.69*
Right-to-left	12.51*	Top-to-bottom	14.75*
Top-to-bottom	13.50*	TLRB	18.99*
TLRB	14.98*	Right-to-left	22.34*
Prose	31.42	Prose	40.48

C.D. = Critical Difference

* Significantly Different From Prose

+ Significantly Different From The TLRB Flowchart.

p < .05.

prose ($\bar{M} = 31.42$). However, groups using flowcharts did not make significantly fewer errors when solving simple problems than the group using the prose. Moreover, the groups using the orthogonal flowcharts did not use significantly less time to view the format when solving simple problems than the group using the TLRB flowchart.

When groups solved complex problems the results were similar to when they solved simple problems. The groups using the left-to-right ($M = 4.06$) and top-to-bottom ($\bar{M} = 4.56$) flowcharts made significantly fewer errors solving complex problems than the groups using the prose and the TLRB flowchart ($\bar{M}$ for both groups = 6.93). In addition, all groups using flowcharts (average $\bar{M} = 17.53$) used significantly less time to view the format when solving complex problems than the groups using the prose ($\bar{M} = 40.48$). The groups using the right-to-left flowcharts, however, did not make significantly fewer errors solving complex problems than the groups using the prose and TLRB flowchart. Finally, the group using the TLRB flowcharts did not use significantly more time to view the format than the groups using the other flowcharts.

Summary of Results. The results indicated that directional orientation, problem complexity, and the interaction between the two effects were significant. The important findings, with respect to separating the factors of the graphic design of flowcharts, were the significance

of direction and the interaction. "Post hoc" comparisons indicated that people perform best using flowcharts with left-to-right and top-to-bottom directional orientations. Groups using these flowcharts made significantly fewer errors and used significantly less time to view the format than groups using the right-to-left flowcharts. Moreover, groups using left-to-right and top-to-bottom flowcharts made significantly fewer errors than the group using the prose. Furthermore, the groups using left-to-right flowcharts used significantly less time to solve problems than the groups using the top-to-bottom and right-to-left flowcharts. Finally, all groups using flowcharts used significantly less time to view the format (an average of 57 percent less time) than the group using the prose.

DISCUSSION

The results of the present study supported a majority of the hypotheses. Directional orientation and problem complexity affected the dependent measures as hypothesized. In addition, as postulated, groups using flowcharts with left-to-right directional orientation performed with fewer errors, required less time to view the format and less time to solve problems. Of the hypothesized interactions, only directional orientation by problem complexity was significant. The main effect of the number of alternatives and the other interactions, however, were not significant.

The main effect of problem complexity significantly effected the ERROR measure. As expected, adding irrelevant statements made complex problems significantly more difficult than simple problems with respect to ERROR. Yet, no differences were found between simple and complex problems for the VIEWTIME and SOLTIME measures. Perhaps reading two irrelevant sentences in the complex problems was not a time consuming task. Further, problem solution time was a measure of the total time used to solve each problem and involved considerable variance. Thus, the problem solution time may have been insensitive to differences in problem complexity. The main effect of problem complexity, however, is less important than effects involving directional orientation which was the principle concern of this

study.

By far, the greatest difference between previous research and the present study was that this study separated the effects of directional orientation and the number of alternatives. The overall tests indicated that performance was affected by directional orientation but not by the number of alternatives. Thus, the significant findings of Kammann's (1974) study may have been due to the direction in which the reader was led rather than the number of alternatives.

Two levels of problem complexity were used to assess possible interactions with the factors of direction and alternatives. Problem complexity by directional orientation, however, was the only significant interaction and affected the VIEWTIME measure. Tukey tests showed that there were no differences among groups when solving simple problems; however, when groups solved complex problems, groups using right-to-left flowcharts used significantly more VIEWTIME than groups using left-to-right or top-to-bottom flowcharts.

Considering the main effect of directional orientation, groups using left-to-right flowcharts made significantly fewer errors and used significantly less time to view the format and to solve problems than groups using right-to-left flowcharts. Moreover, groups using left-to-right flowcharts used significantly less time to

solve problems than groups using the top-to-bottom flowcharts. Groups using the left-to-right flowcharts may have performed well because the flowchart leads the reader in a direction similar to reading patterns. This finding parallels previous research that showed performance improved when people viewed a series of dials from left-to-right (Dasheasky 1964, Lincoln and Averbach 1956).

In further support of the need for directional orientation to be similar to reading patterns, the results indicated that groups using top-to-bottom flowcharts performed almost as well as groups using left-to-right flowcharts. Groups using top-to-bottom flowcharts, however, did not use significantly less time to solve problems than did groups using the right-to-left flowcharts. Perhaps subjects did not have as much experience reading from top-to-bottom as from left-to-right. Reading top-to-bottom flowcharts may be similar to reading lists of items or tabled information. Thus, the data seemed to indicate that subjects performed best when flowcharts led the people in familiar reading patterns.

Groups using the right-to-left flowcharts, in which reading patterns were reversed, made significantly more errors than groups using left-to-right and top-to-bottom flowcharts. Moreover, the directional orientation by problem complexity interaction indicated that groups using right-to-left flowcharts used 34 percent more time to view

the format when solving complex problems than groups using the other flowcharts. Subjects reported that they had difficulties reading statements or questions in decision boxes, which led the reader from left-to-right, and then following a flowchart from right-to-left. Moreover, subjects stated that after reading a statement or question they would begin to follow the line that led away from the box. These problems may have made sorting relevant from irrelevant problem statements and choosing the appropriate alternatives more difficult. In addition, subjects may have had difficulty finding their place in the flowchart after re-reading the problems. To compensate for these difficulties, several subjects using right-to-left flowcharts kept a finger on the view box window to keep their place when reading. This did not occur with subjects who used left-to-right and top-to-bottom flowcharts.

The main effect of the number of alternatives leading from decision boxes was not significant. This non-significant effect may indicate that flowchart designers have some flexibility in choosing the number of alternatives. Increasing the number of alternatives leading from a decision box would allow more information in the decision box. It appears that subjects may be able to consider several alternatives and more information without degrading performance. Note, however, that there was no evidence that increasing alternatives and information would help

performance. It is possible, however, that at some point an increase in the number of alternatives may increase the chance of choosing the wrong alternative.

Two non-orthogonal conditions were analyzed and compared with the six orthogonal conditions. One non-orthogonal condition was the TLRB flowchart. This binary flowchart leads the reader from top-to-bottom, to the left and to the right. The group using the TLRB flowchart made significantly more errors than the groups using the left-to-right and top-to-bottom flowcharts. The group using the TLRB flowchart, however, did not use significantly more VIEWTIME than the other flowchart groups.

(There were no significant effects found in the step-down tests for SOLTIME in Analysis II. The addition of the two non-orthogonal conditions increased the error variance for SOLTIME.)

Kammann (1975) found that groups of housewives using a binary TLRB flowchart made significantly more errors than housewives using a multiple alternative left-to-right flowchart. Because no significant effects involving alternatives were found in this study Kammann's results were probably due to the directional orientation of the flowcharts. Subjects in this study explained that checking their accuracy with the TLRB flowchart was difficult because the action boxes were located on the three margins of the page. Moreover, they explained that the TLRB flow-

chart appeared to be complicated and confusing and they had trouble locating their place in the flowchart after re-reading the problems.

The second non-orthogonal condition was prose, presented in paragraphs. The prose used in this experiment consisted of short sentences with no unnecessary words. The group using prose, however, made significantly more errors than groups using the left-to-right and top-to-bottom flowcharts. Moreover, the group using the prose used significantly more time (57 percent more time) to view the format than all other groups using flowcharts. These findings are consistent with the findings of previous studies (Kammann 1975, Blaiwes 1974, and Wright and Reid, 1973) and indicate that presenting instructions in prose has the disadvantages of increasing error and time to view the format.

Subjects using the prose format explained that the sentences in paragraphs, that applied to the problem, were not easy to locate. They would have to sort through the sentences to find the one that applied to the problem. Having to sort through the prose would make choosing an incorrect outcome more likely. Moreover, the sorting process would affect the time used to view the format especially when a number of sentences were read that did not apply to the problem.

Flowchart designers and future research should consider the problems or tasks for which the flowcharts are to be used. Flowcharts may improve performance for only certain types of problems. The problems used in this study had characteristics that may not be found in other problems or tasks. The characteristics include:

1. Problems did not require the subjects to make inferences or assumptions. The list of sentences for each problem contained all the information needed to solve the problem.
2. Subjects did not work with time limits. The time subjects used to solve problems was self-paced.
3. Subjects did not have to use long-term memory. The problems and flowcharts were available to the subjects during the time used to solve each problem.
4. Subjects did not have to read unfamiliar terminology. The problems and procedures involved fictitious university registration procedures and all subjects were registered university students.
5. The problems required cognitive skills but not perceptual-motor skills. Subjects were not required to assemble or disassemble objects.

6. The sentences in the problems could be ordered into a sequence by using the flowcharts. The subjects were not required to use strategies other than sequencing sentences in order to solve problems.
7. All problems were structured to start the subject at the beginning of the flowchart and work systematically through it.

Future research should consider several problems involving the design of flowcharts. Displaying lengthy procedures using a flowchart may be space consuming and require more than one page. Subjects may have difficulties reading from one page to the next. As flowcharts become complex, the subjects may have trouble entering the flowcharts somewhere other than the beginning. Moreover, the graphic structure of the flowchart may be difficult to read if repetitious loops or shape coding are used. Simple graphic designs for flowcharts were used in this study. Future research should consider these added complexities.

Many types of formats for procedural instructions might be compared to flowcharts in follow-on studies. Other research has compared flowcharts to programmed design languages (PDL) or requirements statements language (RSL) for the purpose of presenting designs to computer programmer (Dyer, et.al. 1977; Ramsey, Atwood, and Van Dorn, 1978). These languages involved abbreviated sentences

that deleted all words except those that conveyed the message. The results of these studies showed that RSL and DSL aided in comprehension of a procedure more than flowcharts. Some simplified versions of the language could be compared to flowcharts and presented to other types of users.

Summary and Conclusions. The purpose of the present study was to evaluate two factors in the graphic structure of the flowchart used for a problem solving task. The two factors were: the directional orientation of the flowchart and the number of alternatives leading from decision boxes. Performance was measured using the number of incorrect problem solutions, the time used to view the format, and the time used to solve problems. From these results the following two conclusions can be made:

1. Performance was best when the directional orientation of the flowchart was consistent with reading patterns. The best direction for the graphic structure was from left-to-right.
2. The number of alternatives leading from decision boxes used in this study had no effect on performance.

The results of this experiment indicate that flowcharts are superior to prose presented in paragraphs when used to present procedural instructions. Moreover, the results indicate that flowcharts leading in directions

that are similar to reading patterns should be used.

APPENDIX A.

Practice and Experimental Trial Procedural Instructions and Problems.

All flowcharts were reduced
approximately 68 percent.

The original page dimensions
were 16 x 14 inches.

PRACTICE TRIAL PROBLEMS

1. a. Rick had received a distress signal which was canceled.
b. Alert signals were now being received.
2. a. John received alert signals.
b. There were no other danger signals received.
3. a. Vickie received distress signals.
b. The ship radioed that a fire was burning in the engine room.
4. a. Rick received distress signals.
b. The crew master had been notified.
c. The radio message did not state the nature of the emergency.
5. a. Jane received alert signals followed by distress signals.
b. The helicopter had been dispatched.
c. The ship radioed that smoke and intense heat were pouring through the aft deck hatch.

PROSE PRESENTED IN PARAGRAPHS, EXPERIMENTIAL TRIAL

Registration instructions

Full-time students, having declared their major course of study, must determine whether or not they want required or elective courses. Those students wanting elective and required courses must go to desk A. Students wanting only elective courses must go to desk B. Students wanting only required courses must go to desk C. Finally, students not wanting either elective or required courses must go to room D.

Full-time, first semester students, without a declared major course of study, who need additional general education units, should go to desk E. Full-time students, having attended more than one semester, without a declared major course of study, who also need additional general education units, should go to desk F. Those students without a declared major course of study, who do not need additional general education courses must go to office G.

Part-time students, having declared their major course of study, must determine whether or not they need elective courses. Students needing elective courses should go to desk H. Students not needing elective courses and having their advisor's signature must go to office I. Students not needing elective courses and not having their advisor's signature must go to office J.

Part-time students not having declared their major

course of study need to obtain a permission to register card. Students having their card and who are attending school for their first semester must go to room K.

Students having their card and who have attended school for more than one semester must go to room L. Students not having a permission to register card should obtain one from office M.

Figure 1. Binary left-to-right flowchart.

Figure 2. Binary top-to-bottom flowchart.

Figure 3. Binary right-to-left flowchart.

Figure 4. Binary top, left, right, bottom flowchart.

Figure 5. Multiple alternative left-to-right flowchart.

Figure 6. Multiple alternative top-to-bottom flowchart.

Figure 7. Multiple alternative right-to-left flowchart.

SIMPLE (1 through 15) and COMPLEX (16 through 30) PROBLEMS.

- 1)
 - a. Jana has declared her major course of study.
 - b. She wants elective and required courses.
 - c. She is a full-time student.
- 2)
 - a. Bill wants elective courses but not required courses.
 - b. He is a full-time student.
 - c. He has declared his major course of study.
- 3)
 - a. Carol is a full-time student.
 - b. She does not want elective courses but does want required courses.
 - c. She has declared her major course of study.
- 4)
 - a. Russ has declared his major course of study.
 - b. He is a full-time student.
 - c. He does not want elective or required courses.
- 5)
 - a. Terry needs additional general education units.
 - b. She has not declared her major course of study.
 - c. She is a full-time student.
- 6)
 - a. Renee is a full-time student.
 - b. She does not need additional general education units.
 - c. She has not declared her major course of study.

- 7)
 - a. David is a part-time student.
 - b. He needs elective courses.
 - c. He has declared his major course of study.

- 8)
 - a. Elaine does not need elective courses.
 - b. She is a part-time student.
 - c. She has not declared her major course of study.

- 9)
 - a. Bob is a part-time student.
 - b. He has a permission to register card.
 - c. He has not declared his major course of study.
 - d. This is his first semester.

- 10)
 - a. Becky has attended school more than one semester.
 - b. She does not have her permission to register card.
 - c. She has not declared her major course of study.
 - d. Becky is a part-time student.

- 11)
 - a. Jeff does not have his permission to register card.
 - b. He is a part-time student.
 - c. He has not declared his major course of study.

- 12)
 - a. Anita wants elective and required courses.
 - b. She has declared her major course of study.
 - c. She is a full-time student.

- 13)
 - a. Aron has declared his major course of study.
 - b. He is a full-time student.
 - c. He wants elective courses but does not want required courses.

- 14)
 - a. Rick does not have his permission to register card.
 - b. He is a part-time student.
 - c. Rick has attended three semesters.
 - d. He has not declared his major course of study.

- 15)
 - a. Nannette needs elective courses.
 - b. She has declared her major course of study.
 - c. She is a part-time student.

- 16)
 - a. Roger wants experimental college courses.
 - b. He is a full-time student.
 - c. He has declared his major course of study.
 - d. He needs to enroll in twenty units.
 - e. He wants elective and required courses.

- 17)
 - a. Jane does not want required courses.
 - b. She wants to meet with her academic advisor.
 - c. She has declared her major course of study.
 - d. She is a full-time student.
 - e. She wants elective courses.

- 18)
 - a. Dave has declared a second major course of study.
 - b. He is a full-time student.
 - c. He has applied for financial aid.
 - d. He does not want required courses but he does want elective courses.
 - e. He needs to apply for advanced courses.

- 19)
 - a. Yolanda does not want elective or required courses.
 - b. She has an advanced registration card.
 - c. She has applied for advanced courses.
 - d. She is a full-time student.
 - e. She has declared her major course of study.

- 20)
 - a. Richard has a late registration form.
 - b. He needs additional general education units.
 - c. He is a full-time student.
 - d. He wants a physiology course.
 - e. He does not know what major course of study to declare.

- 21)
 - a. Betty does not need additional general education units.
 - b. She needs upper division courses.
 - c. She has not declared her major course of study.
 - d. She is an undergraduate student.
 - e. Betty is a full-time student.

- 22) a. Vickie does not need elective courses.
b. She wants to attend school in the mornings.
c. She needs parking permits.
d. Vickie has declared her major.
e. She is a part-time student.
- 23) a. Jim is a graduate student.
b. He has declared his major course of study.
c. Jim needs two restricted courses.
d. He is a part-time student.
e. He needs elective courses.
- 24) a. Romero has his permission to register card.
b. He needs two restricted courses.
c. He has not declared his major course of study.
d. He is not going to school full-time.
e. Romero has four incomplete grades.
- 25) a. Joann has attended school for three semesters.
b. She did not attend school last semester.
c. She does not have her permission to register card.
d. Joann needs to declare her major course of study.
e. She is a part-time student.

- 26) a. Audrey needs four evening courses.
b. She has one incomplete course.
c. She does not have her permission to register card.
d. Audrey is not a full-time student.
e. She has not declared her major.
- 27) a. Pete needs to apply for graduation.
b. He wants elective and required courses.
c. He has paid all his fees.
d. He is a full-time student.
e. He has declared his major course of study.
- 28) a. Shelia is a full-time student.
b. She has declared engineering as her major.
c. She needs a class schedule book.
d. She needs to have her professor's signature.
e. She wants elective courses but does not want required courses.
- 29) a. Jason thought he needed to go to room L.
b. He changed his major course of study last semester.
c. He wants required and elective courses.
d. He needs independent study programs.
e. Jason is a full-time student.

- 30) a. Peg is attending school for her first semester.
- b. She has not paid her fees.
- c. She has obtained a permission to register card.
- d. Peg is a part-time student.
- e. She has declared her major.

APPENDIX B.

Instructions to Subjects.

Instructions to Subjects.

The experimenter introduced himself and explained that the instructional materials were being evaluated. The subject heard the following instructions:

The view box will contain two different sets of procedural instructions that you will use to solve a number of problems. The first set of instructions will be used by you to solve 5 problems. I will show you how to use the apparatus and how to solve the problems. Next, you will use a new set of instructions to solve 30 additional problems.

The smaller box, with the sliding door, contains the problems written on index cards. To begin work on a problem, slide the door to the right and remove an index card. Do not move the sliding door again until you finish work on the problem. When you finish work, move the sliding door back into its original position and place the index card in the right-hand compartment. Do not begin the next problem until you are told to do so.

Once you have begun a problem you will need to read the procedural instructions in order to find a solution. To read the instructions, depress the button on the front of the view box. Depress the button only when you wish to read the instructions. When you are not reading the in-

structions (i.e. looking away from the view box) release the button. You may view the instructions and the problems as often as you like, however, you are to view the instructions only when you are reading them.

The experimenter demonstrated the use of the apparatus. The subjects were then told:

Once you have chosen a solution, record your solution on the answer sheet. Record only the letter of the alphabet that is associated with your solution. Should you make any incorrect marks on your answer sheet mark an X over the incorrect answer and then write the correct answer. There is only one solution for each problem. If you cannot find a solution, skip it.

You are now ready to begin. You will obtain the problems in the smaller box and read the instructions in the view box. I will help you with the first few problems. Then you will work a number of problems without my help. Work quickly, I will tell you when to begin each problem.

Do you have any questions?

APPENDIX C.

Assumptions of The Multivariate Analysis of Variance (MANOVA)

Assumptions of the Multivariate
Analysis of Variance (MANOVA)

Multivariate normality. The experimental design involved a sample size of 64 participants including 8 persons for each cell of the 2 x 3 x 2 and the 2 x 8 factorial mixed designs. This produces more than the 10 degrees of freedom for error needed in order to assure multivariate normality of the sampling distribution of means. The provision for two tailed tests was provided in the SAS (Statistical Analysis System) computer program used. That is, the F test provided for a test of differences between means in both directions.

Homogeneity of Dispersion Matrices. Sample variances for each of the three dependent measures were examined for each of the eight groups. The ratios of the smallest to the largest variances for each of the measures and groups did not approach 20 to 1. Tests for homogeneity of covariance matrices were performed through SPSS (Statistical Package For The Social Sciences) Manova. This was done for the measures associated with both simple and complex problems and showed F simple problems $(42, 5186) = .98$, $p > .05$ and F complex problems $(42, 5186) = 1.74$, $p < .05$ for Box's M. This statistic shows significant deviation from homogeneity of covariance matrices for measures associated with complex problems. The power of the test is

so great considering the df, however, that the amount of deviation was considered too small to warrant data transformation. Moreover, the Manova procedure was considered to be sufficiently robust to tolerate the slight heterogeneity encountered in these data.

Outliers. A test for statistical outliers was run on BMD10M (Biomedical Series). No outliers were found at the .001 probability level.

Linearity. Scatter plots of the intercorrelations among the measures associated with simple and complex problems were produced using the SPSS Scattergram. Since none of the scatter plots showed gross deviation from linearity, and since major violations of the assumption of linearity only reduce the power of MANOVA, the decision was made to retain all variables in their original form.

Intercorrelations. The intercorrelations among dependent measures were computed using an SPSS Pearson Correlation and are shown in Table C1. Measures associated with simple and complex problems were averaged together. All three correlations produced by the three measures show statistically significant relationships. Error was associated with the time used to view the format, $r(64) = .50$, $p < .001$ and with the time used to solve problems, $r(64) = .39$, $p < .001$. In addition, the time used to view the format was associated with the time used to solve problems $r(64) = .60$, $p < .001$. None of the intercorrelations were

great enough to indicate multicollinearity among the measures.

APPENDIX D.

Raw Data

RAW DATA

Subject Sex	ERRORS		VIEWTIME		SOLUTION TIME	
	Simple	Complex	Simple	Complex	Simple	Complex
B/LR						
1/M	04	04	16	15	39	47
2/F	04	04	08	14	23	29
3/F	02	03	06	09	22	30
4/F	03	05	12	22	33	57
5/M	05	07	10	18	42	53
6/M	03	06	07	09	13	24
7/M	02	03	08	12	27	33
8/F	03	04	14	23	35	56
B/RL						
9/F	06	04	05	03	44	38
10/M	02	03	15	16	35	60
11/F	04	05	10	18	33	43
12/F	07	06	12	20	31	60
13/M	06	08	17	40	37	53
14/F	06	09	17	35	33	54
15/M	05	07	12	15	36	46
16/M	08	11	23	45	29	48
B/TB						
17/F	02	04	11	13	48	38
18/F	06	08	08	14	31	49

Subject Sex	ERRORS		VIEWTIME		SOLUTION TIME	
	Simple	Complex	Simple	Complex	Simple	Complex
19/M	02	05	13	11	29	32
20/M	04	06	06	07	26	28
21/M	03	04	12	14	47	61
22/F	05	05	15	19	32	54
23/M	03	07	10	18	21	29
24/F	02	03	15	21	28	34
B/TLRB						
25/M	03	05	17	17	53	61
26/F	07	05	14	14	30	33
27/M	06	08	15	21	41	57
28/M	07	06	10	18	32	48
29/M	07	09	27	32	46	67
30/F	06	07	19	28	25	38
31/F	02	04	13	22	29	52
32/F	05	09	16	26	47	71
M/LR						
33/M	04	04	13	17	33	57
34/F	02	03	07	09	12	25
35/F	04	04	08	10	22	31
36/F	04	07	19	21	39	61
37/F	02	02	05	08	21	28
38/M	03	02	06	08	24	28

Subject Sex	ERRORS		VIEWTIME		SOLUTION TIME	
	Simple	Complex	Simple	Complex	Simple	Complex
39/M	02	03	09	12	27	32
40/M	00	04	08	11	23	29
M/RL						
41/F	03	05	11	18	34	46
42/M	06	07	11	13	36	52
43/F	04	06	13	26	29	38
44/M	08	08	11	17	27	47
45/F	04	05	11	20	29	74
46/M	06	08	14	33	32	49
47/F	07	10	20	43	47	59
48/M	05	09	16	38	38	51
M/TB						
49/F	06	07	11	12	32	39
50/F	02	03	13	19	37	59
51/M	01	05	07	08	27	32
52/M	01	03	11	18	32	52
53/M	04	03	11	13	27	39
54/F	03	04	12	14	48	64
55/F	04	04	14	18	35	52
56/M	03	06	13	20	38	58

Subject Sex	ERRORS		VIEWTIME		SOLUTION TIME	
	Simple	Complex	Simple	Complex	Simple	Complex
PROSE						
57/M	06	07	33	42	47	73
58/F	04	08	27	46	38	57
59/M	08	07	31	38	46	60
60/F	04	05	24	40	42	58
61/F	06	06	33	54	43	71
62/F	03	07	38	42	51	59
63/M	05	08	36	39	42	49
64/M	02	05	28	41	37	58