

Selecting and Switching: Some Advantages of Diagrams Over Tables and Lists for Presenting Instructions

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Abstract—Instructions for operating a control panel were presented in five different formats: flowchart, logical tree, yes/no tree, decision table, and list. Subjects had to choose one out of eight buttons, depending on the settings of the control panel. The results show that the decision table resulted in more errors, and that both the decision table and the list took longer than the three other formats, which did not show mutual differences. It turned out that the subjects valued most the format they had been using, except for those who had worked with the list. It is suggested that the users' ease of orientation for a diagram's format, both during reading and after "switching" between equipment and instructional text, explains the differences between the formats.

Index Terms—Diagrams, document design, tables.

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A procedure explains how to do something. More formally, it is an ordered sequence of steps that have to be carried out to reach a goal, to solve a particular problem, or to construct a product [1]. A procedure may consist of simple actions to achieve a goal, but the actions may also be elaborated by adding conditions and specifications about when, where, and how to perform them. If a procedure is presented on paper or on a screen, it is usually meant to support task performance, from operating a machine to preparing a meal. The procedure functions as an "instruction."

One of the factors that makes instructions complicated is that some steps depend on certain conditions, as in the following example:

If the top left switch is in ON position and meter 1 reads less than 3, and display A shows STOP and meter 2 reads 100, then press button 6. But if the top left switch is in ON position and meter 1 reads less than 3, and display A shows RUN, then you should press button 7.

Such complex conditional structures can be simplified by formatting the text appropriately, in particular by using bulleted lists, tables, or diagrams such as flowcharts and logical trees. The spatial position of the elements (top/bottom, left/right), together with graphical symbols, such as bullets, lines, boxes, and arrows, replace verbal conditionals such as *if*, *then*, *while*, *unless*, etc.

Many publications about professional communication recommend

using tables, decision tables, or flowcharts for presenting complex conditions. For instance, Jansen and Steehouder [2] show that flowcharts were more effective than unformatted text ("prose") for informing citizens about a government regulation. Overhoff and Molenaar [3] argue that laws and regulations can be designed and controlled more effectively by converting them into decision tables instead of bureaucratic prose. They recommend decision tables as a tool for jurists who construct and/or evaluate government bills. In a technical context, Horton's [4] chapter on visualizing procedures contains useful advice and convincing examples for applying graphic formats, ranging from simple bulleted lists to complex flowcharts.

LITERATURE REVIEW

Rationales for Graphics What characteristics make graphics useful for presenting instructions? The following important advantages may play a role.

1) *Graphics help selection of relevant information:* In many instructions, particular steps are only relevant under certain conditions and can therefore be skipped if these conditions do not hold (as in the example at the beginning of the article). In particular cases, some of the conditions do not have to be verified, for example:

- If an instruction is of the form "If A or B, then perform action C, otherwise, do D," and condition A turns out to be the case, it is not necessary to verify condition B; action C has to be performed anyway.
- If an instruction is of the form "If A and B, then perform action C, otherwise do D," and condition A turns out not to be the case, it is not necessary to verify condition B; action D has to be performed anyway.

If a procedure has to be efficient (saving time and effort), the reader may profit from "partial processing" of the instructions—i.e., jumping over all the elements that are irrelevant in the specific situation. However, in ordinary texts, it is often difficult to identify these irrelevant elements. Readers have to read and understand the complete procedure before they can decide which elements can be skipped. Experiments by Holland and Rose [5] show indeed that readers checking conditions in ordinary texts do process all the text, without saving time and effort by partial processing.

Certain graphical formats, however, such as flowcharts and decision tables, are supposed to enable partial processing much more easily. Depending on whether a condition holds or not, the reader may proceed by a different "route" to the next condition to be verified or to the outcome of the procedure (the action to be performed). Experiments [6] have confirmed that readers are able to take advantage of graphical formats and that graphic formats take less time for verifying conditions than prose texts. However, if this effect is intended, it is very important that the sequence of the conditions is the most efficient [7].

2) *Graphics reduce the syntactic complexity of the instruction:* Experiments by Holland and Rose [5] suggest that the complexity of instructions outlined above is determined by four factors:

- The number of conditions. The more conditions, the more difficult the instruction is.
- The number of embeddings. The conditions may be coordinated ("A and B and C") or subordinated ("A and B or [C and D]"). If they are subordinated, sentences can easily become ambiguous, e.g., "Press button A if the red light is on or counter X reads 4 and the switch is in the ON position."

- The relation between the conditions. Conjunctions ("A and B") seem to be easier to understand than disjunctions ("A or B").
- Negations ("A and not B"). These are especially important if certain expressions are used, such as *unless*, *provided*, or *except*.

In graphical presentations, complex instructions are split up in single steps, connected by a spatial arrangement of lines and/or arrows. This means that almost all of those four factors are eliminated. Only the number of conditions remains a relevant factor. If the reader adopts a "switching" reading style (see below), even this factor almost becomes irrelevant, because the reader has to read and perform only one element at a time. The number of conditions would only affect the time needed to perform the task, not the difficulty.

3) *Graphics help readers process procedures step-by-step:* A common experience of readers of technical material is that when they start to work with the equipment or the software after reading a long procedure, they find that they have forgotten the first step, and they have to return to the text and reread it. In many cases, it would be easier to switch from the text to the equipment immediately after reading one step, then perform the action, switch back to the instruction to read the second step, etc.

This issue of switching is not restricted to instructions for equipment. In a thinking aloud experiment by Steehouder and Jansen [8], readers had to read a text about a government regulation to discover what this regulation would mean in their particular situation. In this case, the time when they started to apply the information to their own situation was very important. When they switched from reading to applying too early, they made mistakes

because they had not yet read all relevant information. When they switched too late, they had already forgotten the exact content of the text, or they confused the relevant and irrelevant information.

Graphical formats may help readers to switch at the right moment. An experiment by Boekelder and Steehouder [9] suggests that spatial and graphical separation between steps in a text influences the switching behavior of users of technical equipment. However, the facilitating effect of graphic presentations on switching has not yet been investigated in detail. It was tested in the experiment described below.

Of course, graphic formats have some disadvantages as well. They are more laborious to design, and they take up more space on paper or on the computer screen. In documentation for nontechnical people, problems may occur if readers are not used to graphics. Although no evidence has been found that this would affect the effectiveness or the efficiency of the instructions, it might nevertheless influence the appreciation of the documentation by the readers, and, consequently, their willingness to read it carefully.

An important disadvantage of graphic formats might be that some types have a negative effect on the understanding of the procedure by the reader. The overview of the procedure may be lost when readers apply a switching reading strategy, particularly because they skip a number of steps that are irrelevant in their particular situation but might be very important for understanding the big picture. This loss of understanding explains why flowcharts in particular seem to be less suitable when a procedure has to be learned [10].

Differences Between Graphical Formats Perhaps due to the fact that the “graphical approach” never has been challenged seriously,

there is less empirical research in this field than is necessary to understand its effects in detail. Most of the research on tables has to do with searching for numerical data in tables, for example, the many detailed experiments by Patricia Wright in the early 1970s. However, in relations to conditions-and-action information, the research is quite limited, although unambiguously supporting the superiority of graphics to prose. Wright and Reid [10] compared instructions in several formats: ordinary (“bureaucratic”) prose, flowchart, table, and list. Subjects in the experiment had to answer questions about a fictitious space voyage, using one of the instructional formats. They concluded that, for complex problems, flowcharts and tables were more effective (they led to fewer errors) than both prose and list. For simple problems, there were no differences in effectiveness, but the table format turned out to be more efficient: it took less time to find the answer.

In another experiment, Wright [11] compared prose, table, and logical tree formats for explaining to examination candidates which questions they should answer. In this experiment, the advantages of the graphical presentations were less clear. A table or a logical tree did not produce fewer errors than prose, and the prose version even took less time than both graphical formats. Wright explains this by pointing out that in this experiment the instructions **did not contain irrelevant information**, which the instructions in the previous experiment did. In other words, the advantages of graphical presentations seem to lie primarily in the fact that they help readers apply partial processing; they select from the instructions what is relevant for their actual situation.

In an ingenious and very carefully conducted experiment (that regrettably never has been published), Holland and Rose [6] used three

formats for presenting instructions of the type “*If A and B or C and D, then press button X*”—where *and* and *or* were systematically alternated, and negations (*not-A*, *not-B*, etc.) were also considered. The instructions were presented in prose, algorithm (flowchart), and question list formats. The latter consists of a sequence of questions such as: *Does A apply to you? If yes, go to nn, if no go to mm*, where *nn* and *mm* were either the next question to be answered, or the final instruction *to push button X*.

The results of their experiment showed that both flowcharts and lists were more effective and more efficient than prose. Both were equally effective, but flowcharts were more efficient. Holland and Rose conclude that both lists and flowcharts enable the reader to partially process the instructions easily. Moreover, their results show that moving from one question to the other takes less time if the questions are linked graphically (as in the flowchart) than if they are connected verbally (by cross-references like “*Go to nn*”).

Michael and Hartley [12] present an overview of eleven experiments (including the Wright and Reid experiment) that compared flowcharts with other formats. They conclude that flowcharts yield better results than other formats in the following cases:

- if there are complex combinations of conditions;
- if there are complex problems;
- if it is important to separate relevant information from irrelevant information;
- if it is not necessary to memorize the instructions or the problem to be solved;
- if the flowchart is oriented from left to right and from top to bottom (however, as far as we know, no experiments have been done in cultures with a right-left orientation of the alphabet, so this conclusion may be limited).

Michael and Hartley indicate that the most important drawbacks of flowcharts are that they are more complex to design than prose and that sometimes readers have difficulties in reading flowcharts.

Switching Between Instructions and Equipment In the experiments reviewed here, the effects of graphical formats (table, flowchart, list) have always been tested in situations where the conditions could be verified either by applying information from memory (in the experiments of Holland and Rose, e.g. “*If you are married and over 45 ...*”), by realizing what the subjects want (“*If you want to ...*”), or by applying task information (e.g., in the experiments by Wright “*What means of transport is to be used if ...*”). However, users often have to verify the current state of external equipment (meters, switches, codes in displays, etc.), as in the example at the beginning of this article. This may complicate the situation in two respects.

First, readers have to decide at what moment they should switch from the instructional text to the equipment, and back. Users may decide first to read the entire instruction, and then verify the state of the equipment. However, it is more likely that they read step-by-step and verify each step immediately after reading, as is suggested by another unpublished experiment of Holland and Rose [5]. Graphical formats may influence the switching behavior of readers because they show the edges between the steps better than continuous prose.

Secondly, since readers are drawn away from the instruction to inspect the equipment, it is important that when returning to the text, they can find the exact place where they have to proceed. The format of the text should facilitate their orientation at that moment. Graphical formats clearly support this process better than continuous prose. However, it is not clear

which of the graphical formats is preferable in this respect.

RESEARCH DESIGN

Research Purpose The purpose of the experiment reported here is to explore the relative effectiveness and efficiency of several graphical formats for tasks that include

- the need to verify a number of conditions, and
- the need to switch from the instructional document to the equipment to be used for the task.

Overview Two different control panels of a fictitious spacecraft were presented alternately on a computer screen. The panels consisted of a number of switches, check lights, meters, and displays, and a numbered row of eight buttons at the bottom. The subjects had to click one of these buttons with the mouse, depending on the settings of the meters and the texts of the displays. Which button to click for a particular panel setting was explained by instructions on a second screen. The format of these instructions differed between subjects; each subject was confronted with either flowcharts, logical trees, yes/no-diagrams, decision tables, or lists.

The subjects were able to look at either the instruction or the control panel by pressing or releasing the space bar. The mouse clicks and the actions of the space bar were registered in a log file.

Five Instructional Formats Compared in the Experiment In the experiment, five graphic formats of an instruction were investigated. (The original materials used in the experiment were in Dutch.)

- A flowchart (Fig. 1): a series of yes/no questions, connected with arrows. For instance: *Is the top left swift ON? Yes/no.* The reader has to follow either the yes-arrow or the no-arrow to reach the next question and

eventually the outcome. In this flowchart, all yes-arrows point to the right, all no-arrows point down (the last one with an angle to the right).

- A logical tree (Fig. 2): again a series of questions, connected with arrows, but in these cases, the questions are not yes/no-questions but questions with two alternatives. For instance: *What does the display A show? RUN/STOP.* As with the flowchart, the reader has to follow the appropriate arrows to reach the next question or the outcome. In this logical tree, all lines point down, and no arrows are used.

The difference between a flowchart and a logical tree is not often made in the literature as we do here—usually, the terms are used without a clear distinction (as well as the term algorithm). It seems that those formats are mostly considered as equivalents. There seems to be no sound base for hypothesizing about differences. An exception is the experiment by Barnard *et al.* [13]: form-fillers needed more time to answer questions such as *Are you married? Yes/no* than questions of the type *I am single/married*. The latter type, however, is not a question, and the answers are by definition complementary, at least in most countries (one is either single or married, but in the case of the display it is theoretically possible that there are more possibilities than RUN or STOP).

If we would find any differences between the flowchart and the logical tree, then there may be two explanations. The differences might be caused either by the layout (two directions versus one direction) or by the formulation of the questions (yes/no versus alternatives). Therefore, we decided to include a third type of graphic in our experiment:

- A yes/no tree (Fig. 3): this has the graphic form of the logical

tree, but the *yes/no* questions of the flowchart.

- A decision table (Fig. 4): this consists of columns indicating parts of the equipment and rows that represent the setting that these parts can have. By

choosing the right row from left to right, the reader reaches the appropriate outcome in the rightmost column.

- A list (Fig. 5): this consists of vertically ordered numbered actions, each followed

by a number of conditions, after which either a route-instruction (“Go to number . . .”) guides the reader to the next question, or the appropriate outcome is given.

A continuous prose version is

Fig. 1. Flowchart.

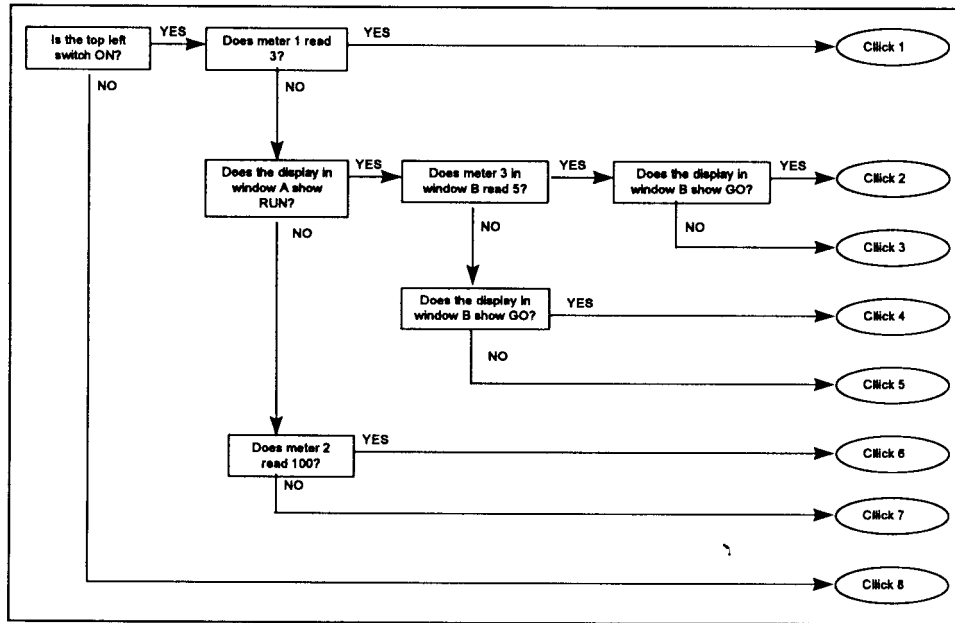
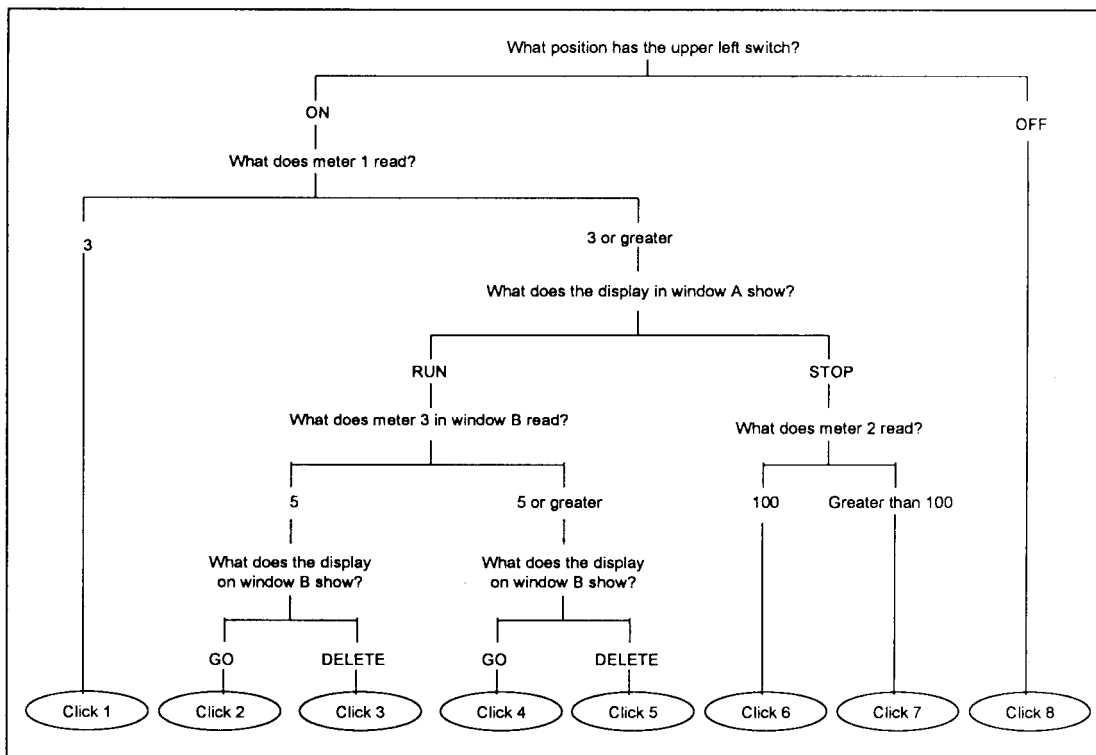


Fig. 2. Logical tree.



outside the scope of this study because of the unanimous results of the experiments reported in the literature [12]. Graphical formats proved to be more effective and efficient than prose in all exper-

iments. Thus it does not make sense to investigate this again.

Control Panels Two different control panels were used in the experiment (see Fig. 6(a)-(c)). Each

panel was shown with five different settings (i.e., a combination of positions of meters, windows, indicators, etc.), which resulted in ten cases. Three cases required verification of two elements before

Fig. 3. Yes/no tree.

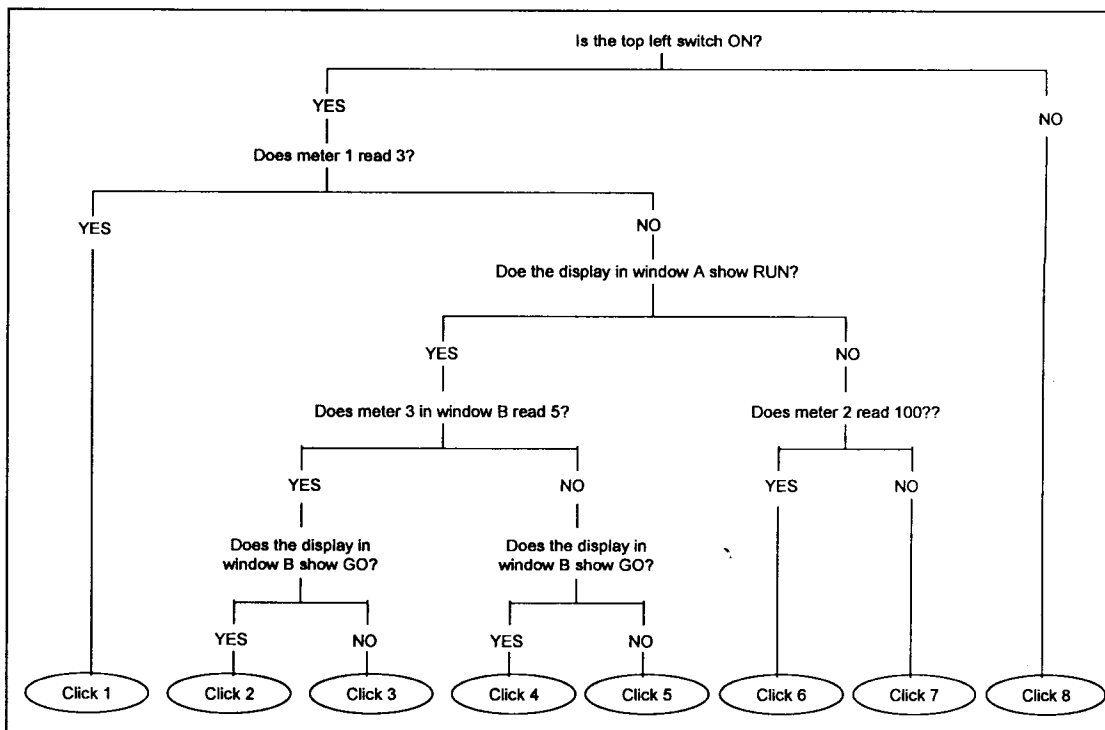


Fig. 4. Decision table.

Is the top left switch read ON?	Does meter 1 read 3?	Does the display in window A show RUN?	Does meter 3 in window B read 5?	Does the display in window B show GO?	Does meter 2 read 100?	Click
YES	YES	-	-	-	-	button # 1
	NO	YES	YES	YES	-	button # 2
			NO	NO	-	button # 3
			YES	YES	-	button # 4
			NO	NO	-	button # 5
			-	-	YES	button # 6
	-	-	NO	button # 7		
NO	-	-	-	-	-	button # 8

a button could be clicked. Three cases required verification of four elements, and four cases required verification of five elements. This variation would make it possible to investigate whether the subjects partially processed the instructions. Cases that only require two verifications would require less time than settings that require four or five verifications.

The control panels were displayed on a screen in front of the subject. After the subject had clicked one of the buttons, the message *next assignment* was displayed. After the subject clicked OK, the next status of the control panel was shown.

Subjects Subjects were 99 students (36 female, 63 male) at the University of Twente. 71 of them were engineering students; 28 were social sciences students. The subjects received NFL 10 (approx. \$5 US) for their cooperation. The subjects were randomly assigned to one of the graphical formats.

Procedure The experiment was fully controlled by a computer program except for a questionnaire. The introduction to the experiment (see Fig. 6) was displayed on the screen. The introduction was formatted in short paragraphs, which were displayed one after another. By clicking *Continue* the subject could proceed to the next paragraph. *Click on OK to start the first assignment* was displayed at the end of the introduction.

There were two different procedures (one for each panel) that indicated which of the eight buttons had to be clicked. The instructions (in one of the formats discussed above) were presented on a second computer screen, left in front of the subject.

Only one of the screens was visible at any one time during the experiment. When the subjects wanted to look at the instructions, they had to press the left screen's space bar. At the same moment, the control panel at the right was made invisible. When the space bar was released, the instructions became

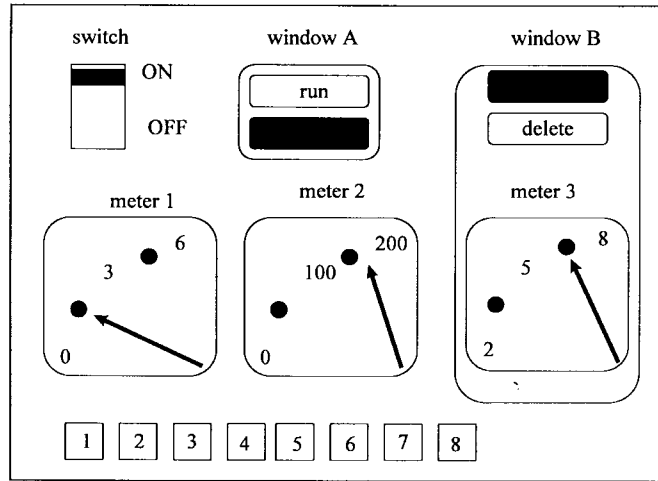
invisible, and the control panel was visible again. So the subjects were able to look at either the instructions or the control panel, not both. This experimental setting made it possible to keep track of reading times, as well as of the exact moments and frequencies of switching between instruction and control panel. It turned out that (after little practice) switching between the two screens was very easy.

The subjects were presented in turns with one of the control panels that had a different setting of the switches, the meters, and the lights each time. The subjects had to decide which of the eight buttons on the bottom of the control panel had to be clicked with the mouse. After clicking, a different task—unrelated to this experiment—had to be carried out. (A different control panel was presented for this in-between task, along with ordinary prose instructions. The subject had to click some button and key in some codes.) When this task was

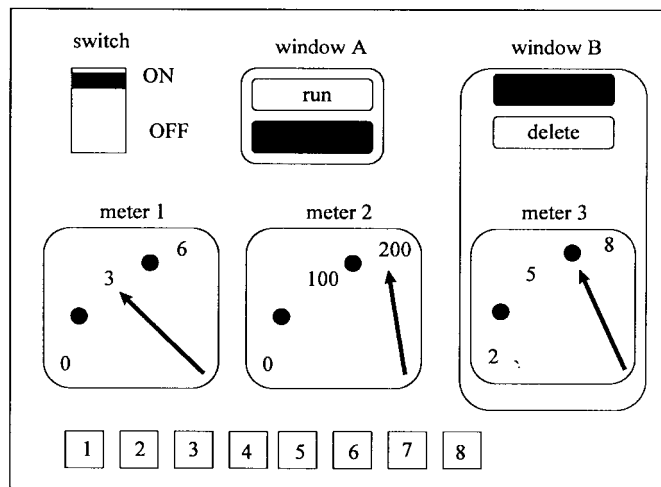
Fig. 5. List.

- | | |
|---|--|
| A | Look at the top left switch
If the switch is ON, go to B
If the switch is OFF, click button # 8 |
| B | Look at meter 1
If it reads 3, click button # 1
If it reads greater than 3, go to C |
| C | Look at the display in window A
If it shows STOP, go to D
If it shows RUN, go to E |
| D | Look at meter 2
If it reads 100, click button # 6
If it reads greater than 100, click button # 7 |
| E | Look at window B
If meter 3 reads 5 and the display shows GO, click button # 2
If meter 3 reads 5 and the display shows DELETE, click button # 3
If meter 3 reads greater than 5 and the display shows GO, click button # 4
If meter 3 reads greater than 5 and the display shows DELETE, click button # 5 |

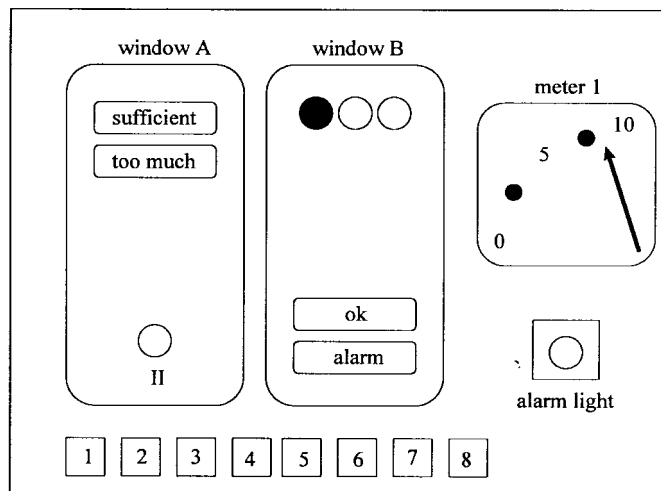
Fig. 6. (a) Sketch of control panel #1 with settings that require five elements to be verified and button #5 to be clicked; (b) sketch of control panel #1 with settings that require two elements to be verified and button #1 to be clicked; and (c) sketch of control panel #2.



(a)



(b)



(c)

completed, the next assignment appeared on the screen.

All the subjects' actions were logged by the computer: pressing and releasing the space bar, as well as clicking one of the buttons with the mouse. The log files were converted into a record that showed exactly when and for how long the instructions were read and which buttons were clicked at the end of each assignment.

Each subject completed ten different assignments, five for each control panel (see Fig. 7 for some examples). Each assignment started with different settings of one of the control panels.

The first assignment of the test was the same for all subjects; this task was used to practice and has not been included in the analysis

of the results. The order of the other nine assignments was varied between the subjects.

The format of the instructions was a between-subjects variable. Each of the subjects was confronted with only one of the five formats.

RESULTS

Effectiveness The first question to ask is: how accurate are the results of the different formats? After all, time differences are only relevant if the number of correct answers is equal. The number of errors (wrong buttons clicked) per format is shown in Table I. A one-way ANOVA showed a difference ($F = 3.550, df = 4, p < .01$). Tukey's test showed that the number of errors made with the decision table differs from the number of errors

made with the logical tree, the yes/no tree, and the list. Thus the decision table produces less accurate results than the other graphical formats.

Efficiency The efficiency of the formats can be expressed in two measures: task time (= time between starting a new assignment and completing it by clicking one of the buttons) and reading time (= time during which the space bar is pressed down, i.e., the time that the instruction could be seen, and the panel was hidden).

The mean task times (in seconds) are presented in Table I. A one-way ANOVA showed a significant difference ($F = 5.201, df = 4, p < 0.001$) between the formats. Tukey's test showed that the list was less efficient than the logical tree and that

Fig. 7. Introduction of the experiment (translated fragment).

Several control panels of a spacecraft will shortly appear on the screen you are currently watching. The panels contain buttons that can be clicked with the mouse. Imagine you are the commander of the spacecraft and you have to handle the buttons for several tasks.

The procedure is as follows. When the control panel appears, the meters and switches are in certain positions. This indicates a particular situation. You have to react on this situation by clicking one of the buttons numbered 1 to 8, at the bottom of the control panel. You can find which button you should click in the instructions that are presented on the left screen.

After you have clicked the button, the next control panel will appear on the screen.

TABLE I
NUMBER OF ERRORS, MEAN TASK TIME, AND MEAN READING TIME PER ASSIGNMENT
(STANDARD DEVIATIONS IN BRACKETS)

	Flowchart n=19	Logical tree n=19	Yes/no tree n=18	Decision table n=22	List n=21
Mean number of errors per assignment	.7 (1.4)	.5 (.7)	.6 (.7)	1.8 (2.1)	.5 (1.0)
Mean task time per assignment	23.1 (4.7)	23.8 (3.8)	24.4 (5.1)	28.3 (6.9)	29.3 (6.5)
Mean reading time per assignment	12.1 (3.8)	12.2 (1.9)	13.0 (4.0)	15.1 (4.0)	17.2 (4.3)

the decision table was less efficient than the flowchart.

The mean reading times (in seconds) are also presented in Table I. Again, a one-way ANOVA showed a difference ($F = 7.050, df = 4, p < 0.001$). Tukey's test showed that the list was less efficient compared to the flowchart, logical tree, and yes/no tree.

The analysis so far has been presented for each assignment without considering the number of elements that had to be verified to decide which of the buttons had to be clicked. As stated above, some tasks required two, some required four, and some required five verifications. Table II presents the task times for the assignments by the number of verifications required.

An analysis of variance with repeated measures yielded significant time differences between the five graphical formats ($F = 5.61, df = 4, p < 0.001$), and between the three types of assignments ($F = 226.96, df = 2, p < 0.001$). Tukey's test showed that:

- For assignments that required two verifications, the list was less efficient than the flowchart and the logical tree was less efficient than both the flowchart and the yes/no tree.
- For assignments that required four verifications, the list was less efficient than both the logical tree and the flowchart.
- For assignments that required five verifications, no differences were found.

Table III shows the mean reading times for the assignments, by the

number of verifications that had to be verified.

An ANOVA with repeated measures showed significant differences between the reading times for the five graphical formats ($F = 7.47, df = 4, p < 0.001$) as well as differences between the three types of assignments ($F = 219.74, df = 2, p < 0.001$). Tukey's test showed that:

- For assignments that required two verifications, both the list and the decision tree were less efficient than the flowchart or the yes/no tree.
- For assignments that required four verifications, the list was less efficient than the flowchart, the logical tree and the yes/no tree.
- For assignments that required five verifications, the list was

TABLE II
MEAN TASK TIME PER ASSIGNMENT WHEN TWO, FOUR, OR FIVE VERIFICATIONS WERE REQUIRED
(STANDARD DEVIATIONS IN BRACKETS)

	Flowchart n=19	Logical tree n=19	Yes/no tree n=18	Decision table n=22	List n=21
Assignments requiring two verifications	12.9 (3.5)	15.6 (4.2)	13.0 (2.1)	18.6 (7.1)	17.6 (4.3)
Assignments requiring four verifications	23.1 (5.3)	23.6 (5.0)	24.4 (7.7)	28.4 (8.6)	31.3 (11.7)
Assignments requiring five verifications	28.0 (6.5)	28.1 (5.1)	29.3 (6.2)	33.1 (8.1)	33.7 (7.4)

TABLE III
MEAN READING TIME PER ASSIGNMENT FOR ASSIGNMENT THAT REQUIRED TWO, FOUR, OR FIVE VERIFICATIONS
(STANDARD DEVIATIONS IN BRACKETS)

	Flowchart n=19	Logical tree n=19	Yes/no tree n=18	Decision table n=22	List n=21
Assignments requiring two verifications	5.8 (2.1)	6.6 (2.2)	5.2 (1.7)	8.3 (4.3)	8.8 (2.9)
Assignments requiring four verifications	11.9 (3.9)	11.9 (3.3)	13.5 (5.4)	15.0 (5.8)	18.8 (8.2)
Assignments requiring five verifications	15.3 (5.3)	15.3 (2.6)	16.6 (4.9)	18.6 (4.8)	20.3 (4.9)

less efficient than both the flowchart and the logical tree.

Preferences After the experiment, the preferences of the subjects for the various formats were collected. The subjects were asked to rank printed examples of the formats by preference: the best one in the first place (1 point) and the worst one in the last place (5 points).

The results are presented in Table IV. These results indicate that the subjects preferred the format they had used during the experiment. The only exception to this is for those who had used the list. They preferred the flowchart and the yes/no tree to the list.

CONCLUSIONS

The results of the experiment show clear differences between the five graphical formats. The decision table yielded more errors than all the other formats. This can be explained by the fact that it requires cognitive processing in two directions: rows and columns. It seems that readers sometimes choose the wrong row (or "lose" their row), so that they come to the wrong outcome. Despite the fact that a decision table requires relatively little space, it is evidently not the most appropriate format.

Our conclusion that working in two directions is more difficult than working in one direction is consistent with the results of an experiment by Wright and Fox [14], who asked subjects to look up numbers in a "matrix table."

The differences in the efficiency measures (task times and reading times) show that the list format (and to some extent also the decision table) are less efficient than the other formats. For the decision table, this may also be explained by the bidirectional orientation: users have to orient themselves twice within the table, which takes extra time. The fact that the list is less efficient than the other formats suggests that verbal cross references ("Go to ...") are more difficult to follow than the graphic features (arrows and lines) in the diagrams.

No significant differences were found between the flowchart, the logical tree, and the yes/no tree. Apparently, neither the direction of the lines and arrows made any difference, nor the type of question (yes/no versus open). But it should be taken into account that the open questions in this experiment had only two answers. If the number of possible answers increases ("*What color is the sign:*

red, green, blue?"), then the differences between the flowchart and the logical tree become more substantial. In order to make a choice between three or four options, two yes/no questions are needed, while only one open question is needed to offer the same number of alternatives. Other experiments [15] suggest that one choice of four alternatives can be made more quickly than two choices of two alternatives each. Consequently, in such cases, a logical tree may be more efficient.

As to the subjects' preferences for the formats, it is interesting to see that this depends on their previous experience. The format they worked with was valued most, except for the list. It is striking that even the subjects that had worked with the table preferred it to the other formats, despite the difficulties they seemed to have with using it (of course, the subjects were not aware of the fact that the table turned out to be less effective than the other formats). These results indicate that users' preferences for certain visual formats may not reflect their ability to use them effectively. Thus it might be unwise to base design decisions on preferences of users. On the other hand, users' preferences may be important as to

TABLE IV
MEAN PREFERENCE RANKING OF THE FIVE GRAPHIC FORMATS RELATED TO THE FORMAT THE USER USED DURING THE EXPERIMENT

	Ranking of the flowchart	Ranking of the logical tree	Ranking of the yes/no tree	Ranking of the decision table	Ranking of the list
Subjects who had used the flowchart	1.7	3.0*	2.7*	3.7*	3.8
Subjects who had used the logical tree	2.7*	1.5	2.2	4.4*	4.3*
Subjects who had used the yes/no tree	2.3	3.0*	1.6	3.9*	4.3*
Subjects who had used the decision table	2.3	3.4*	2.7*	2.1	4.5*
Subjects who had used the list	2.3	3.0*	2.5*	4.2*	3.1

bold = most preferred format (=lowest number) in the row

* = differs significantly ($p < .05$) from the most preferred format in the column

their willingness to use and follow instructions—which is why we still consider them as relevant.

Our results indicate that it is important that readers of instructions can orient themselves in the chosen format. Two types of orientations were important in the experiment. First, it was important that the reader was able to “follow” the route from one verification to the next. As we have seen, this was more difficult with the two-dimensional decision table, and it took more time with the list. But since the subjects had also to switch between the instruction and the control panel, a second moment of orientation was important. Suppose the reader reads one step (“Does the counter read 3?”), then switches to the control panel to verify this, and then returns

to the instructions to read the next verification. The reader has to orient him- or herself to find the place where he or she left the instruction. This switching problem may be of little influence when it is easy to remember the complete instruction as a whole. However, if the instructions consist of many steps, it seems likely that the influence will be more substantial.

Our data do not allow for any conclusions to be drawn about the relative influence of both types of orientation problems. A considerable number of subjects turned out to be able to complete their task after one (long) period of studying the instruction. They inspected the control panel, switched to the instruction, and returned to the control panel and clicked on the button immediately. Other

subjects switched more frequently between control panel and instruction. More research is needed to find out how important the influence of both types of orientation is.

What conclusion can be drawn for the design of instructions in practice? Our experiment suggests that flowcharts, yes/no trees, and logical trees are more appropriate for instructions than decision tables (which yield more errors) or lists (which take more time and are appreciated less by users). As long as the individual verifications have only two outcomes, these three formats seem to be equally appropriate, but it seems important to restrict instructions to one format, since users prefer the format they have become familiar with.

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