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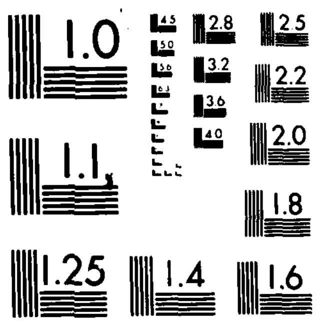

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How Experts and Nonexperts Operate Electronic Equipment from Instructions

David E. Kieras, Mark Tibbits,
and
Susan Bovair

Technical Report No. 14 (UARZ/DP/TR-83/ONR-14)

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Three questions were addressed in an experiment in which subjects followed instructions to complete tasks involving several pieces of electronic equipment: (1) Two instruction formats were compared: a hierarchical menu format containing natural chunks of instructions was not superior overall to a simple step-by-step instruction format. The menu format was superior only if the subject was familiar with the type of device, and was sometimes

substantially inferior otherwise. (2) Experts were compared to nonexperts, and found to be faster overall, and able to operate equipment with fewer instructions in the menu condition. They were also faster when complex physical actions were involved. Thus, there were both specific and general effects of expertise. (3) Evidence was sought that knowledge of how to operate equipment was schematic. It was expected that when subjects in the menu format condition operated a device without selecting any instructions to read, their sequence of actions should correspond to stereotyped schema-like patterns. This occurred only weakly, suggesting that even experts operate everyday devices in a problem-solving mode, rather than by retrieved complete procedures.

Abstract

Three questions were addressed in an experiment in which subjects followed instructions to complete tasks involving several pieces of electronic equipment: (1) Two instruction formats were compared: a hierarchical menu format containing natural chunks of instructions was not superior overall to a simple step-by-step instruction format. The menu format was superior only if the subject was familiar with the type of device, and was sometimes substantially inferior otherwise. (2) Experts were compared to nonexperts, and found to be faster overall, and able to operate equipment with fewer instructions in the menu condition. They were also faster when complex physical actions were involved. Thus, there were both specific and general effects of expertise. (3) Evidence was sought that knowledge of how to operate equipment was schematic. It was expected that when subjects in the menu format condition operated a device without selecting any instructions to read, their sequence of actions should correspond to stereotyped schema-like patterns. This occurred only weakly, suggesting that even experts operate everyday devices in a problem-solving mode, rather than by retrieved complete procedures.

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How Experts and Nonexperts Operate Electronic Equipment from Instructions

David E. Kieras, Mark Tibbits,
and
Susan Bovair

This report describes results from an experiment which was designed to assess three questions about how people operate a piece of equipment from written instructions. The questions deal with instruction format, expertise, and the organization of prior knowledge, in a task in which subjects must follow a set of instructions in order to complete a task involving an electronic device.

The first question is one of instruction format (see Smith & Goodman, 1982). This is the difference between whether the format or layout of the instructional material forces the user to execute each step in order, or whether the instructions allow the user to pick and choose the material to be read and executed. In this experiment, one group received step-by-step instructions that were presented a single step at a time, and the subject had to read every step. The other group received a hierarchical menu of instructions, in which the subject could either execute the task with only a high level description, or could request more detail. In this way, the subject would only have to read the instructions that he or she felt was necessary to execute the task. The rationale of this manipulation is that an expert subject could take advantage of the hierarchical menu format, because large portions of the task would be familiar. However, a nonexpert subject would have to read all of the instructions anyway, so the menu would not be of any great advantage. Furthermore, there should be relatively little difference between experts and nonexperts on step-by-step instructions, because in both cases all of the steps must be read.

The second question is the nature of expertise effects. While expertise has been heavily studied (see Chi, Feltovich, & Glaser, 1981; Chi & Glaser, in press), it has not been examined in the context of operating electronic equipment, a domain of great practical importance. Generally, it is expected that experts would complete the tasks faster, and read fewer steps in the menu condition. However, this could depend on the device under consideration. Only experts would be familiar with some devices, but even the nonexperts should be able to operate other devices easily. Likewise, even nonexperts should know some things about almost any device, such as how to turn it on. Thus, it was expected that there would be an interaction of subject expertise, experience with the exact device, and the nature of particular steps in the instructions. The basic question about expertise effects is whether there are general effects of expertise, or whether they are specific to the individual devices involved. For this reason, several devices of widely differing familiarity were used.

The third question concerns the nature of the prior knowledge that subjects have about devices. In Kieras (1982) it was suggested that knowledge of devices is organized in the form of schemas. These schemas would include knowledge not only of how to recognize a particular type of device, but also its typical structure and operating procedures. If device knowledge is organized by schemas, there should be clear patterns in the data obtained in this experiment. Menu choices should follow patterns that would be expected from schematic device knowledge. If subjects operated the equipment entirely from prior knowledge, without reading instructions, which happened in many cases, then their behavior should follow some pattern that can be described in terms of device schemas.

The basic manipulations performed in this study were as follows: several devices were used, which included two every-day devices, two devices familiar to only experts, and two novel devices familiar to neither experts nor nonexperts. The subjects were either experts, who typically had several years of working experience in electronics, or nonexperts, who were ordinary college students. A questionnaire was used to confirm the subject's classification, and to assess each subject's experience with the individual devices used in the experiment. The two instruction formats were either a step-by-step format or a hierarchical menu format. The terminal nodes of the menu hierarchy consisted of the exact same individual instruction steps as were used in the step-by-step format. The variables measured were the total completion time for each task on each device, the completion time for each individual step in the step-by-step instructions, and in the menu condition, the individual menu choices, and their completion times. The subjects' behavior was recorded on videotape to allow detailed scoring on the subjects' activities while performing the tasks.

METHOD

Materials

Devices. The six devices used are described in Table 1. The radio, cassette recorder, VOM, and oscilloscope were of a standard make. The phi phenomenon demonstrator was professionally built, but in general construction style it appeared to be a "home-brew" amateur job. The physiological stimulator is a standard piece of apparatus in a physiological psychology lab, but as the ratings confirmed, it was essentially unfamiliar to all subjects. Notice that all of the non-everyday devices were relatively old-fashioned, being from the vacuum-tube era. The devices were prepared before presentation to each subject by setting all controls to incorrect positions so that in order to complete the

Table 1
Devices Used in the Experiment

Device	Description
1. Radio	A portable AM-FM radio, with built-in AC adapter, antenna, volume, tone, tuning, and band controls.
2. Recorder	A portable audio cassette tape recorder, with keyboard tape controls, red record interlock key, and volume control. Supplied cassette was not fully rewound.
3. VOM	A standard volt-ohm-milliameter, with a supplied resistor to measure.
4. Oscilloscope	A dual-trace triggered-sweep oscilloscope with standard audio signal generator and connecting cables.
5. Phi Phenomenon Demonstrator	A device that flashes two connected neon bulbs alternately at various rates and phase relationships.
6. Physiological Stimulator	A large device with several dial-multiplier sets that produce pulses of specified magnitude rate, and duty cycles; a neon bulb is connected to the output to indicate the pulses.

task, each control would have to be properly set.

Instructions. A major goal in composing the instructions was to allow the menu and the step-by-step instructions to be easily compared to each other. This was done by preparing the materials so that the terminal steps in the menu instructions were exactly identical to the steps comprising the step-by-step instructions, and were worded and displayed identically.

The menu instructions made up a hierarchy of natural "chunks" of the operating procedure. Determination of the chunks was done intuitively. It is clear from some aspects of the results that some of the chunks chosen were in fact natural units; however, the data do not definitively confirm the chunk classification.

Each set of instructions began with a statement of the task that the subject had to accomplish. This main task statement was specific enough that the subject could, if he or she had adequate prior knowledge, complete the entire task from just this statement. However, the main task statement did not describe how the controls on the device had to be set or operated. Table 2 lists the tasks that were to be performed on each device, in the same wording as they were shown to subjects.

Subjects

The nonexperts were recruited by campus and newspaper advertisements, and were paid $5 for participating. As shown by the experience questionnaires administered to the subjects, only one expert subject was inadvertently recruited by this method. The expert subjects were recruited by advertisements directed at electronics experts. In all cases, the subjects obtained were highly experienced in electronics; the typical expert had several years experience as an electronics technician in the military. Twenty subjects were recruited by each method, but in the analyses used below, the classification was corrected, to yield nineteen nonexperts and twenty-one experts. Since earlier studies seemed to suggest that there were strong sex differences among nonexperts, and female electronics experts were extremely hard to locate, all subjects used in this experiment were male.

Design. The instruction format condition was determined at random for each subject. Each subject carried out the six tasks on the six devices in the same instruction format condition. The device tasks were done in a fixed order, which is the order in which the devices are listed in Table 1. This order was chosen to present the tasks and devices in order of decreasing familiarity, and increasing apparent complexity within each level of familiarity.

Table 2

Task	Main Task Statement
1.	Listen to Station KUAT-FM (90.5 FM) at medium volume on the portable radio.
2.	Record the words "testing. . . 1, 2, 3" on the cassette recorder, and play the words back at medium volume.
3.	Measure the resistance of the resistor using the volt-ohm meter.
4.	Use the signal generator and the oscilloscope to display about two AC wave cycles on the oscilloscope screen.
5.	Use the phi phenomenon demonstrator to flash the lights at 5 CPS (cycles per second).
6.	Use the stimulator to flash the neon light at a frequency of 1 CPS (cycles per second) with a flash duration of .7 seconds and a delay of .5 seconds.

Apparatus and Procedure

Each subject was run individually, and was seated in a small room before a table. On the right-hand end of the table was a standard video terminal, on which a laboratory computer displayed the instructions. The left-hand portion of the table was occupied by the device. A videotape recorder recorded all of the subject's activity. The instructions were presented one step or menu at a time with the subject tapping the space bar or typing a choice number to go on to the next display. The laboratory computer recorded the amount of time that the subject left each instruction step or menu on the screen. Due to the nature of the equipment, and the prohibitive scoring effort involved, it was not practical to distinguish the time the subject spent reading from the time the subject spent carrying out the instructions. Thus, the laboratory computer was able only to record e *completion time* for each step, defined as the total reading p s *execution time* for the instruction step. The videotape r rding was used to determine what subjects actually did on each s o.

The devices were brought into the room or a time, and the subject then carried out the task on the devic When the subject had reached the end of the instructions, the experimenter returned and checked that the task had been carried out correctly, in terms of whether the final correct result was achieved. The device was then removed, and a new device brought in. Subjects who did not achieve the proper final result were asked to repeat the task; however, the data from these repeated tasks were later dropped from the analysis.

Due to inadequate training of the experimenters, on some trials the equipment was being moved in and out of the room while the clock was running, making the *completion* time record of the first instruction unreliable. It is believed that these events are not confounded with any of the experimental manipulations, so the analysis of *total* completion time would be conservative due to the extraneous variability. Examination of the video tapes shows that the subjects were visually inspecting the devices while they were being brought in, and so these times reflect the total time that the subjects interacted with the devices to complete the task.

RESULTS

Total Completion Times

Analysis method. The total completion time for each subject on each task was calculated as the total elapsed time from the presentation of the main task statement until the experimenter had confirmed that the task was completed correctly. Data from tasks were dropped in which the subject did the entire task more than once, or failed to do the task at all correctly. Out of the total of 240 task attempts, 14 were thus dropped. Due to the unequal group sizes, missing data, and unbalanced device experience factor, the total times were analyzed using stepwise multiple regression.

The subject's expertise group, instruction format condition, and subject's experience with the individual device were represented as dummy variables. The device experience variable was based on the questionnaires that each subject filled out. If the subject indicated any actual usage experience with the device, then the device experience dummy variable received a value of one; otherwise a value of zero was assigned. The device factor was represented as a set of five dummy coded variables with the radio being used as the baseline. Following the method suggested by Pedhazur (1982) for mixed designs, a variable whose value is the subject's mean total completion time over the six devices was included. The between-subjects factors and interactions were entered first in the equation, followed by the subject's mean time variable, followed by all of the within-subject factors and interactions. The analysis was hierarchical, in that main effects were forced into the equation before interactions.

All of the interactions between subject experience, device experience, and instruction format condition were represented, but only instruction format condition and subject expertise group were allowed to interact with the device factor; device experience was not allowed to interact with the device factor. The rationale for this decision is that the device experience variable is already specific to individual devices, so interactions between individual device experience and individual device dummy variables would be difficult to interpret.

Note that subject expertise and specific device experience in these data are only slightly correlated ($\underline{r}$=.13), and the interaction between subject expertise and device experience was not significant. Thus these two factors make practically independent contributions to the total completion times. Two of the devices were familiar to everyone, and two were unfamiliar to almost everyone, resulting in these two variables being nearly orthogonal.

With a total of 23 variables in the equation and 163 degrees of freedom in the residual, 81.5% of the variance in the total completion times was accounted for. This extremely high figure is due to two factors: the subject's mean completion time accounted for approximately 15% of the variance, and the device factor accounted for about 50% of the variance. This is clearly due to the fact that the devices varied substantially in number of steps in the tasks, and thus the completion times vary systematically over an extremely wide range. The effects to be discussed below were all tested for significance at the .05 level, using the "F-to-remove" statistic, which is a conservative estimate of the significance of an individual variable as if it were the last to enter the equation.

Main effects. Table 3 shows the means for the various main effects that were significant. The subject expertise variable was quite significant; experts were about one third faster in completion time than nonexperts. There was no significant main effect of instruction format condition, even though the menu condition averaged about 30 seconds faster. This means that, counter to intuition, the menu format was not reliably superior overall to the step-by-step format. This is probably a result of the fact that while fewer steps were read in the menu condition, more material has to be read in addition to the individual steps. The device experience factor was significant; being familiar with a specific device led to a 30% improvement in completion time. As would be expected, there is a very strong main effect of devices.

Interactions. The interaction between device experience and instruction format condition, shown in Table 4, was significant. The menu instructions are actually slower than the step-by-step instructions if the device is not familiar, but substantially faster than the step-by-step instructions if the device is familiar. Thus, not only do the menu instructions allow the user to take advantage of prior knowledge more than the step-by-step instructions, but the lack of prior knowledge means that the extra "overhead" in menu instructions, plus mistakes made as a result of skipping instructions, actually slows down task completion.

The interaction of instruction format condition and device, whose means are shown in Table 5, was significant. For the radio, recorder, and phi demonstrator, the menu condition produced faster results than the step-by-step condition. However, the VOM, oscilloscope, and stimulator produced the opposite effect. This is probably due to the fact that these are devices which were especially difficult for nonexperts, exaggerating the effect of the extra material in the menu format. Table 6 shows the interaction between devices and subject expertise group, which was also significant. Here it is clear that the oscilloscope and VOM were especially hard for the nonexperts compared to the experts.

The three-way interaction between subject expertise, condition, and device was significant, and illustrates the key result. The means are shown in Table 7, which includes the percent gain resulting from using the menu instructions instead of step-by-step, for nonexperts and experts on each device. One clear result is that the experts benefit from the use of the menu format on all devices except for the stimulator, where there is a substantial impairment in performance. This is probably due to the fact that since this was a complex and novel device, the experts' attempts to operate it without reading much of the instructions often led them down "garden paths." For example, one expert plugged indicator light into the wrong jack, and then spending a long time trying to set the controls to light it. With the nonexperts, the two expert-familiar devices, the VOM and the oscilloscope, produced much longer completion times in the menu instructions compared to the step-by-step. Since many of the nonexpert subjects claimed experience in using the VOM, their longer completion times in the menu condition may be similar to

Table 3
Main Effects in Total Time Data

Effect	Means	Significance
Expertise		
Nonexperts	314.0	**
Experts	214.4	
Device Experience		
Non-familiar	319.4	**
Familiar	223.0	
Instruction Format		
Step-by-step	274.4	NS
Menu	247.1	
Devices		
Radio	137.1	**
Recorder	166.2	
VOM	256.8	
Oscilloscope	511.9	
Phi Demonstrator	118.8	
Stimulator	343.3	

Table 4
Total Time (Secs) as a Function
of Device Expertise and Instruction Format

Device Experience	Instruction Format: Step-by-step	Menu
Not Familiar	307.8	331.0
Familiar	254.4	185.1

Table 5
Total Time (Secs) as a Function
of Instruction Format and Device

Format	Radio	Recrdr	Device VOM	Oscil	PhiDem	Stim
Step-by-step	185.7	201.3	230.1	504.3	210.5	314.4
Menu	88.4	131.0	297.8	521.9	167.0	375.5

Table 6
Total Time (secs) as a Function
of Subject Expertise and Device

Expertise	Radio	Recrdr	Device VOM	Oscil	PhiDem	Stim
Nonexpert	165.8	188.7	342.8	649.0	230.3	367.8
Expert	111.0	145.7	175.8	396.4	151.2	321.3

Table 7
Mean Total Time for each Device,
Instruction Format, and Expertise Group

	Radio	Recrdr	Device VOM	Oscil	PhiDem	Stim
Nonexpert						
Step-by-step	224.3	216.3	270.8	604.3	260.4	359.5
Menu	100.9	158.2	462.8	723.6	196.9	378.0
% Gain	55%	27%	-71%	-20%	24%	5%
Experts						
Step-by-step	147.0	186.4	189.5	404.4	160.6	269.2
Menu	78.3	108.8	156.3	387.4	142.6	373.5
% Gain	47%	41%	17%	4%	11%	-39%

the "garden path" effect obtained for the experts with the stimulator. Namely, a little familiarity with a device is a dangerous thing; it can lead to longer completion times if instructions are not followed. The elevated time for these subjects in the menu condition with the oscilloscope is harder to explain.

Conclusion. These results demonstrate that the virtues of the two instruction formats are heavily dependent upon the user's general expertise and also the familiarity with the specific device. In general, the interactions seem to be due mostly to the specific familiarity with the device, as opposed to the subject's general expertise. That is, the fact that the interaction between device experience and instruction format was significant, but the interaction between subject expertise and instruction format was not, suggests that the advantage of menu instructions is a matter of specific familiarity with the device, and not general expertise. Electronic experts may not do better with the menu instruction format unless they have specific familiarity with the device in question. Alternatively, if the device is unfamiliar, experts can benefit from menu instructions if the device is simple, such as the phi demonstrator, but not if it is complex, such as the stimulator.

On the other hand, the significant main effect of subject expertise, even with specific device experience taken into account, is important. Experts were generally faster than nonexperts at operating the equipment, regardless of its familiarity. Other aspects of the results suggest that this is due not just to faster execution of actions, and also to better organized and more efficient actions as well.

Menu Choices

Number of frames read. Table 8 shows the mean number of frames (displays of instruction steps or menus) read in the menu condition for each group and each device. For example, both experts and nonexperts read only one frame for the radio, namely the frame that contains the main task statement, but nonexperts chose to read an average of 50.4 frames of information for the oscilloscope task, while experts read an average of only 1.2. These data were subjected to a multiple regression analysis similar to the above one, with the factors being subject expertise, device experience, and devices, and interactions of subject expertise with device experience and individual devices were allowed. The results are summarized in Table 9.

There were strong main effects of device, with the VOM, oscilloscope, and stimulator requiring many more frames than the radio, which was taken as the baseline. The key results were that neither subject expertise nor device experience, nor their interaction, were significant predictors of the number of frames read, once the main effects of device and the interaction of subject expertise with device were taken into account. As shown in Table 8, the VOM, oscilloscope, phi demonstrator, and

Table 8
Mean Number of Frames Read in the Menu Condition
for Each Expertise Group

Group	Radio	Recrdr	VOM	Oscil	PhiDem	Stm
Nonexperts	1.0	1.0	32.5	50.4	18.2	47.8
Experts	1.0	1.0	3.1	1.2	3.4	21.9

Table 9
Regression Analysis on Number of
Frames Read in the Menu Condition

Variable	Coefficient	Std. Coef.	F-to-Remove
CONSTANT	10.1		
SUBJECT EXP.	0.0	.0	0.00
DEVICE EXP.	-9.1	-.231	3.99
DEVICE 2	0.	-.0	0.
DEVICE 3	29.5	.516	45.40
DEVICE 4	46.5	.839	113.19
DEVICE 5	9.1	.184	2.49
DEVICE 6	38.7	.751	43.98
SUB EXP X DEV2	0.0	.0	0.00
SUB EXP X DEV3	-26.3	-.360	20.82
SUB EXP X DEV4	-45.3	-.618	61.52
SUB EXP X DEV5	-14.8	-.224	8.68
SUB EXP X DEV6	-25.9	-.373	25.15

Notes

R2 is .85 with 12 variables and *N*=107. Device 1 (Radio) is used as the baseline for dummy coding of Device factor.

stimulator all required many fewer frames for experts than for nonexperts. The main effect of device experience was marginally significant. Thus, it is clear from these results that the menu condition allows experts to benefit by permitting them to read only a few frames.

Choice Patterns. The specific pattern of frame choices for each device was considered in terms of the menu hierarchy for each device. The intended organization of the menu instructions was that the levels in the hierarchy would correspond to the natural chunks in the operation of the device. However, contrary to the goals of the experiment, the evidence to support this claim is very limited in these data. In order for there to be natural chunks in the operation of the device, the device must be familiar to the subject. However, if the device was fairly familiar to the subject, the subject would need to read very few frames, often only the main task statement frame, and thus there would be few choices to reveal which portions of the menu hierarchy were familiar and which were not. Perhaps different devices would have yielded more useful data.

However, there were some interesting patterns in the choices. Figure 1 illustrates the best example. The figure shows the menu hierarchy for the phi demonstrator in simplified form. The terminal portions of the tree consist of the sequence of actual steps that were identical to the step-by-step instructions. In each box is shown the proportions of nonexperts and experts who read the material in the box. Thus, for example, the top-level box corresponds to the frame that states the main task. Almost all subjects then read the main menu which contains four items: powering up the device, attaching the lights, setting the mode, and adjusting the CPS dial. However, only 40% of the nonexperts and only 10% of the experts felt it was necessary to get the more specific information about powering up the device, and almost none of the subjects required the step-by-step instructions about how to plug in the device and turn it on. The other devices that also involved these steps also had this general pattern. Very few subjects, even nonexperts, required the specific instructions on plugging in and turning on the device. This was true for the oscilloscope and signal generator combination, and also true for the stimulator, which was a very complicated and unfamiliar device.

Another effect that appears in Figure 1 is the tendency for nonexperts to learn while doing similar activities. Notice how 50% of the subjects required the step-by-step instructions for plugging in light A, but only 10% of them went on to read the instructions for how to plug in light B. A similar effect appears in the oscilloscope task, in which fewer nonexpert subjects required the instructions for plugging in and turning on the second piece of equipment than for the first piece of equipment. The obvious implication of this effect is that subjects are not simply executing these instructions as they read them, and then forgetting the instruction content when they proceed to the next instruction. Rather, they seem to be able to take the content of

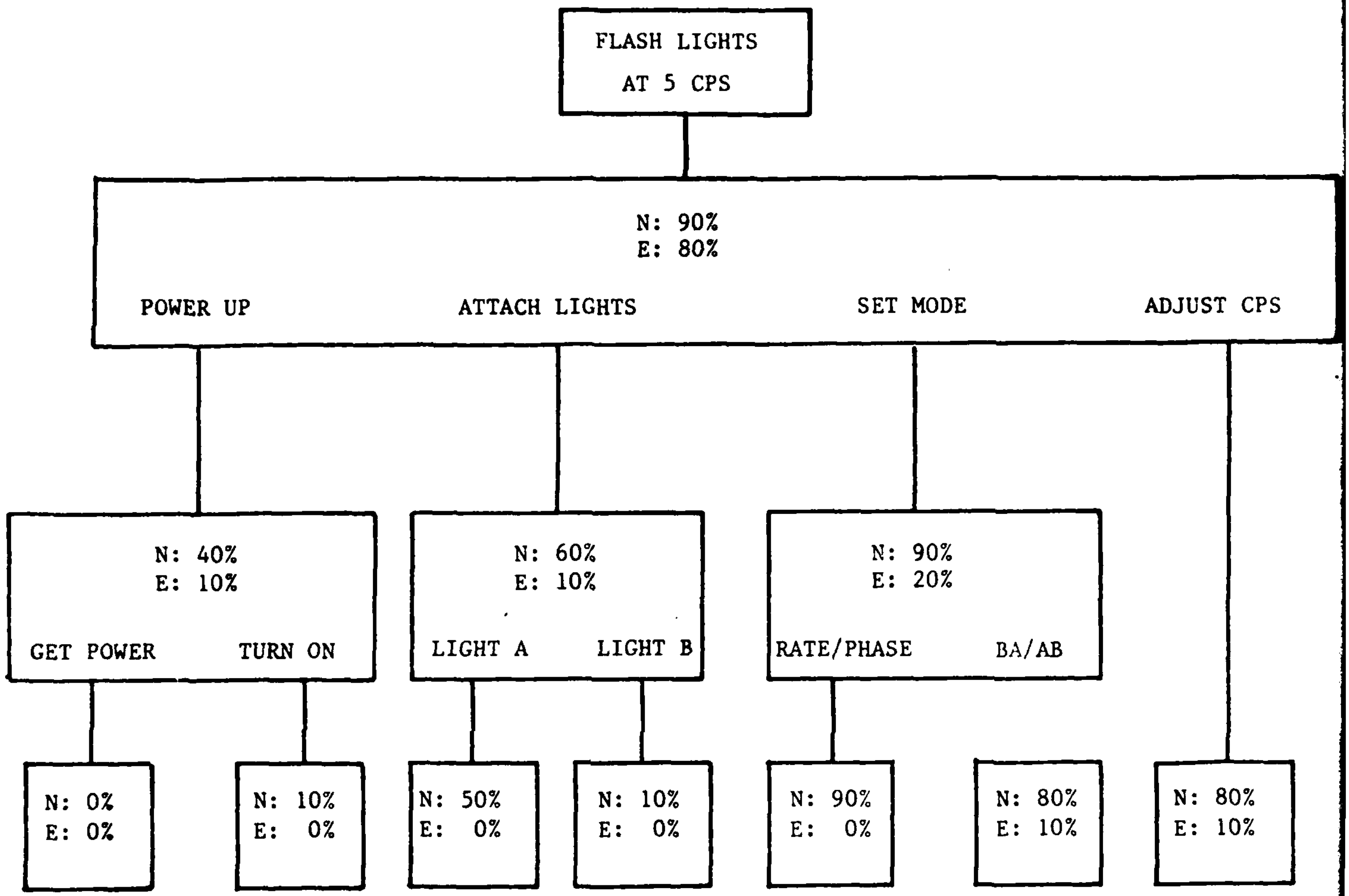


Figure 1. Proportion of menu choices made at each menu level for experts (E) and nonexperts (N) on the phi phenomenon demonstrator.

one instruction and generalize it immediately to apply to a similar situation. However, these results are too limited to shed much light on this issue. Further work is clearly needed.

Step Completion Times

Analysis method. A regression analysis was done to determine which factors predict the amount of time taken to complete individual steps in the step-by-step condition. The videotape scoring was used to eliminate the times for individual steps that were defective. In addition, the times on the very first step in the instructions were not included since in some cases, these times were contaminated as described above. This left a total of 3008 individual step times for the analysis. Each instruction step was classified according to a set of categories, shown in Table 10, which are the general types of actions stated by the instructions. These categories were each represented by a dummy variable, with the ISIMP category being used as the baseline. The video tapes for each subject were scored according to the action actually carried out by the subject on each step. The scoring categories for the actions are shown in Table 11. These were also represented with dummy variables, with SKIP being used as a baseline. In order to examine the chunking properties of the step-by-step instructions, the variable MENU was defined, which reflects the proportion of times the subjects in the menu condition read the corresponding step. This variable took on a value that depended on whether the subject was an expert or a nonexpert. If the subject was an expert, then the value of MENU was the proportion of experts that viewed the corresponding step in the menu condition. Likewise, for a nonexpert, the MENU variable was the proportion of nonexperts that viewed that instruction.

An additional variable that reflected properties of the instructions was the number of words in each instruction. This variable should not be taken to reflect comprehension time, since its coefficient is far too large; rather, it provides a crude measure of the overall amount of information in the instruction. Additional variables entered into the analysis were the subject's expertise group, and the device experience variable, as described above. The subject expertise variable was allowed to interact with all of the instruction characteristic variables and the action variables. As before, the order of entry in the stepwise analysis was hierarchical, and the conservative "F-to-remove" statistic is reported. Finally, since this was a mixed design, the subject expertise variable was entered into the equation first, followed by a subject mean variable, then by the within-subjects variables.

Step time results. A summary of the analysis is shown in Table 12. Note that the coefficients must be interpreted in terms of the fact that all other factors are in the equation. There was a substantial effect of subject expertise (SUBEXP), in which experts read the instructions on the order of 1.6 seconds faster per step than nonexperts. Also, the step times differed

Table 10
Dummy Variables Used to Code Instruction Contents

Variable	Description and Example
ILOC	Locate a part of the device (locate the power switch)
IADJ	Setting a control (turning knob to DC)
ISIMP	A simple action (flipping a switch)
IEFFECT	Adjusting a knob to produce a certain effect (zeroing ohms scale)
ICOMPH	A complex physical action (plugging in a cord)
IEXPH	A complex physical action familiar to an expert (zeroing a meter)

Table 11
Dummy Variables Used to Code Subject's Actions

Variables	Description
DO	Action same as instruction
SKIP	No action carried out
LOOK	Subject looks at device
LOC	Subject "locates" a part of device (e.g. touches it)
ACT	Subject engages in some action other than above

Table 12
Regression Analysis on
Completion Times for each Step in
the Step-by-step Condition

Variable	Coefficient	Std. Coef.	F-to-Remove
CONSTANT	-15.45		
SUBEXP	-1.63	-.110	36.96
SMEAN	1.00	.249	242.29
DO	4.11	.277	9.54
LOC	2.46	.139	4.55
ACT	7.30	.188	129.20
ILOC	1.86	.126	5.43
IADJ	4.60	.116	45.99
IEFFECT	3.16	.093	18.92
WORDS	.57	.339	366.98
ICOMPH	14.46	.247	154.99
IEXPH	6.42	.156	42.66
EXPCOM	-5.52	-.065	11.19
EXPXPH	-5.78	-.100	24.31
MENU	1.71	.091	8.59

Notes

R^2 is .4075 with 19 variables and N=3008. Five variables are not shown because the F-ratios were nonsignificant. See text for explanation of variables. Values for SUBEXP are based on only SUBEXP in the equation, before SMEAN and the within-subjects variables are added.

substantially depending both on which actions that subjects actually performed, and also in the properties of the instructions themselves. This result in itself is not too surprising. However, it is noteworthy that two of the strongest (as shown by the standardized regression coefficients) instruction factors are the number of words in the instruction (WORDS), and whether the instruction required a complicated physical activity (ICOMPH). Instructions that required physical activities that are familiar only to experts, such as adjusting the zero adjust screw on the VOM (IEXPH), also took significantly longer, even though such cases were fairly rare.

The key results are the interactions of expertise with two of the instruction characteristics, namely, complicated physical activities (EXPCOM), and expert physical activities (EXPXPH). This suggests that not only are experts faster across the board, but they are especially fast at certain complicated physical activities. Informal observation of the video tapes seems to confirm this. Nonexpert subjects often spend a lot of time fumbling with cords and connectors, while experts seem to know exactly what they are doing in these physical activities, and proceed smoothly and precisely.

An additional key result is that the MENU variable was significant. The coefficient means that with all other factors in the equation, a step that was always read in the menu condition took about 1.7 seconds longer than one that was never read. Assuming that the menu choices reflect the familiarity of procedure "chunks," the amount of time taken to complete a step is thus a function of its predictability on the basis of prior knowledge.

Knowledge-based Operation

In Kieras (1982) it was proposed that people's knowledge of electronic devices is organized as a hierarchy of schemas, which would contain, among other things, schematic information on how to operate the corresponding class of devices. It is natural to suppose that just as a story schema specifies the order of appearance of items in a story, that a device schema would specify the order of the steps for operating the device. Thus, when subjects operate a device based only on their knowledge, there would be a stereotyped sequence of behavior corresponding to the procedural schema for operating the device. Some of the data from the menu condition was suitable for examining this issue; there were many cases where subjects attempted to operate the device after receiving only the main task statement, without requesting further instructions.

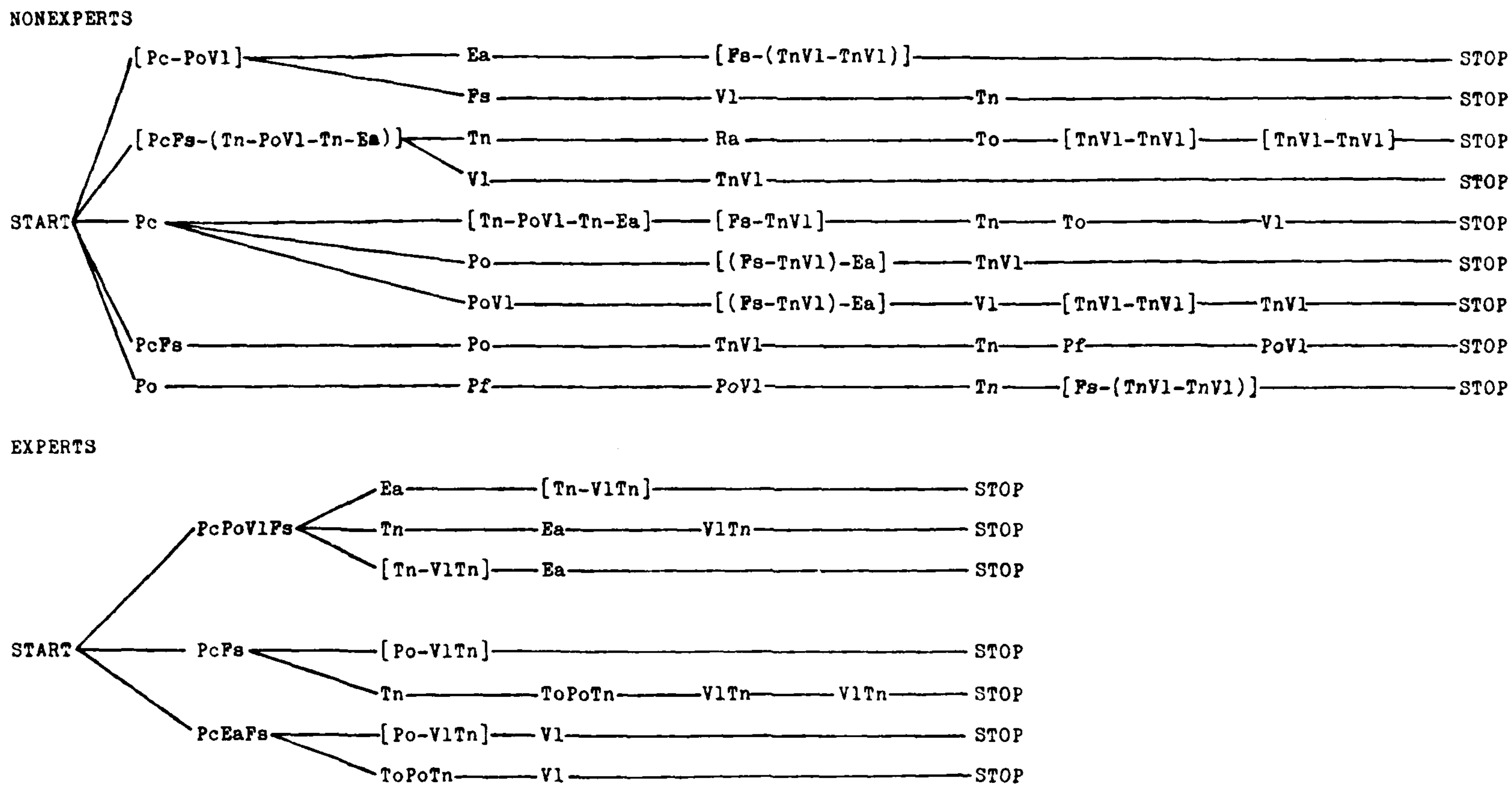
Analysis method. The videotape record of the subjects' behavior was scored in terms of the individual activities that subjects performed, such as operating a certain control. Data were dropped for subjects who got confused in the task or did it incorrectly in some way that would invalidate the data. Both experts and nonexperts all operated the radio and cassette recorder without any further instructions in the menu condition. Seven experts on the radio and nine nonexperts were thus available. For the cassette recorder there were eight usable behavior sequences from each group. With three other devices, only experts operated the device without instructions. For the VOM, oscilloscope and signal generator combination, and the phi phenomenon demonstrator, there were five, eight, and eight such subjects.

The method of analyzing this sequence data was to locate sequences of activities that occurred at least twice, and then express the sequences that subjects performed with as few terms as possible by referring to these common sequences. More specifically, the sequence data was represented as a transition network tree diagram, in which the nodes represent either individual actions or action "subroutines," and a single path through the tree diagram represents the activities of a single subject. See Figure 2 for an example. Each action is represented by a two-letter symbol, and action subroutines by combinations of these symbols. The depth of combination is indicated by the notation; concatenated symbols are the shallowest level, with brackets and parentheses indicating deeper levels of subroutines.

In order to construct this transition diagram, all actions except specific control operations were deleted from the behavior stream. Thus, for example, activities of locating (touching) a control, or looking at various parts of the device were dropped from the analysis. The resulting sequences were then subjected to a sorting process in which common sequences were identified and then the data regrouped according to the sequences, and the process repeated until no more sequences could be formed.

Once these sequences were defined, the behavior patterns for all of the subjects could be rewritten as a tree diagram, in which all subjects begin at the origin and then branch out according to the first action or sequence subroutine that they perform, and then branch out further depending on their individual actions. Since all subjects eventually did some action that was different from that done by any other subject, eventually the trees all had the same number of branches as there were subjects.

Pattern results. In Figure 2 is shown the top level diagram for the sequences for the nonexperts and experts on the radio. Notice how the nonexpert network seems to be "bushier" than the expert network, and also appears to have more different subroutines. Beyond the preference for initially plugging in and turning on the radio, there seems to be little in the way of an interpretable pattern in the nonexpert sequences. However, there is a basic pattern to the expert sequences. The subjects who followed the bottom two major branches first "set up" some portion of the radio before turning it on. The subjects following the upper branch turned on the radio immediately and then proceeded to make a series of adjustments to it. Thus, even with as simple a device as a radio, there seem to be two major methods of operating it: the first is setting it up and then turning it on, followed



Pc=plug in power cord	Po=Turn power on	Vl=adjust volume control
Fs=select FM band	Ea=extend antenna	Tn=adjust tuning
To=adjust tone control	Pf=turn power off	Ra=retract antenna

Figure 2. Behavior sequences for expert and nonexpert subjects operating the radio without instructions.

by adjusting it, and the second is turning it on, then setting it up and adjusting it. Within each of these two major patterns there are many minor variations.

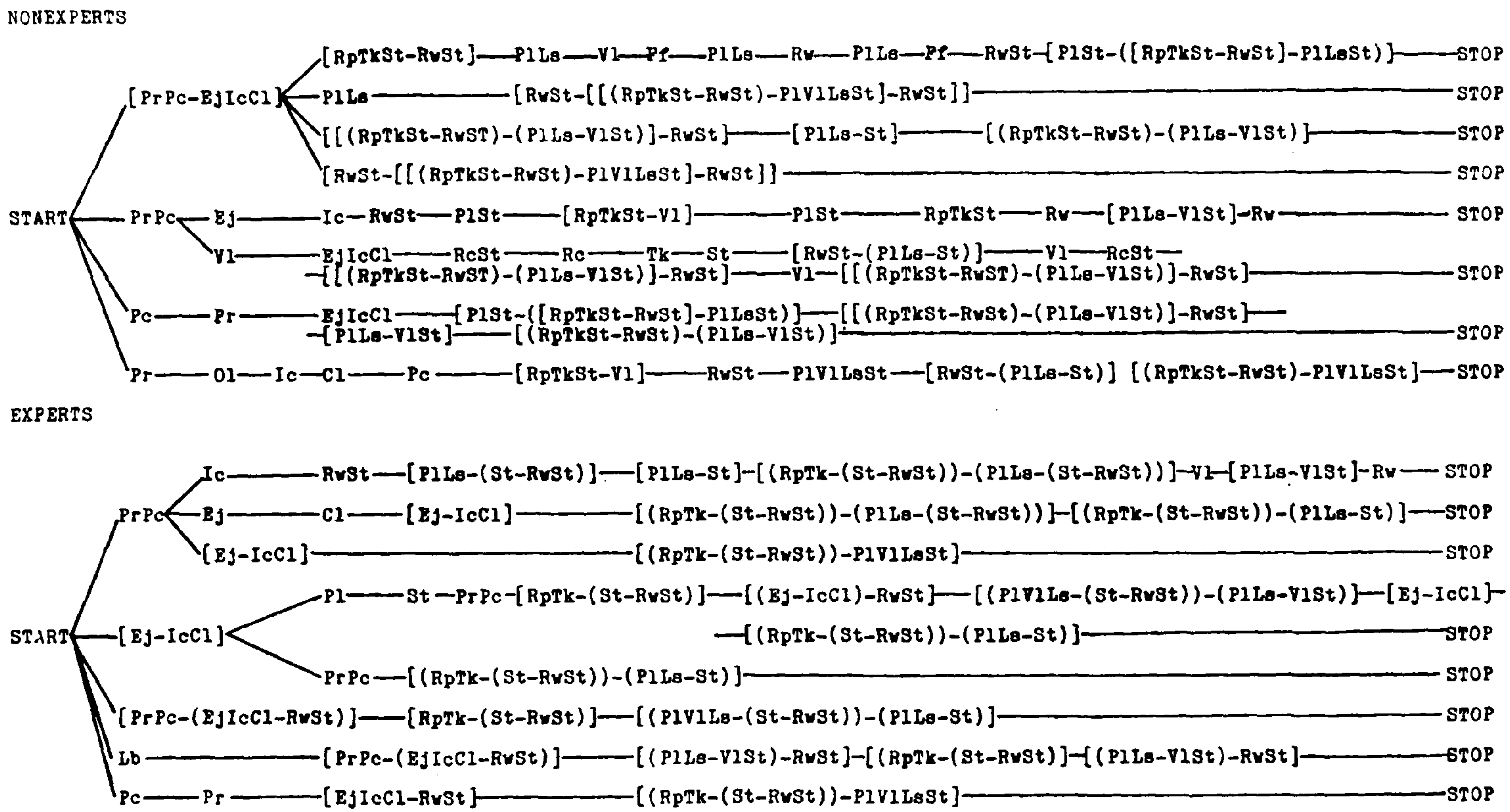
A similar apparent difference between experts and nonexperts appears with the cassette recorder in Figure 3. Overall, the experts appear to produce shorter and simpler sequences than the nonexperts. Thus the experts in both the radio and the tape recorder appear to have more consistent and shorter behavior sequences. Some quantitative comparisons between the expert and nonexpert transition networks were very intriguing, but none of them reached statistical significance.

It should be noted that some of the complexity of the tape recorder behavior sequences is probably due to the fact that the tape cassette was deliberately given to the subjects in a condition in which it was not fully rewound. Since the subjects' task was to record "testing one-two-three" on the tape and play it back, this confused some subjects if they rewound the tape all the way back after recording as one normally would. Thus, some subjects, even experts, had to make more than one attempt to record the tape. Perhaps this complexity is a reflection of the fact that the tape recorder was not left in a schematic state; that is, the normal state for a tape cassette is that it is fully rewound.

An important conclusion is that if there is an apparent difference between experts and nonexperts, even on these everyday devices, then experts are better even at operating everyday devices than nonexperts. This presents a serious problem for future studies of electronics expertise, because it suggests very strongly that nonexperts can not be used as subjects of such studies even if very familiar devices are used.

A further result that follows from an examination of these two networks, and was also clearly apparent with the other devices is that there is in fact very little stereotypy in the specific behavior sequences. Figure 4 presents the transition network for the five experts using the VOM. Notice that the number of subroutines is quite small, and there is an almost immediate branching of the tree into unique paths, one for each subject.

Because of the extreme length of the sequences for the oscilloscope and signal generator combination, Figure 5 presents a truncated and condensed version of the full transition network. For example, the term CRT means any control activities having to do with adjusting the CRT trace on the oscilloscope, which could involve any sequence of the five controls. Likewise, TB refers to any sequence involving adjustments to the oscilloscope's time base, which also involved several controls. It should be noted that even after this extreme condensation the paths through the network again branch into unique patterns very quickly. The phi phenomenon demonstrator in Figure 6 also shows a relatively quick branching into unique paths.



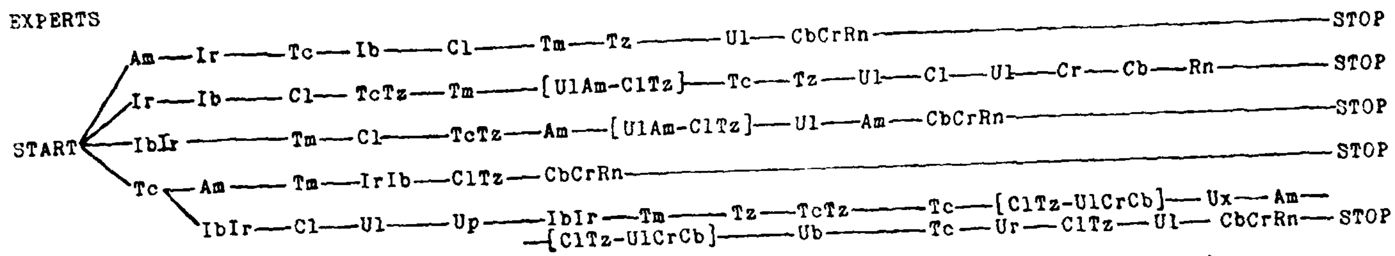
Pr=plug cord into recorder
Rw=rewind key
Vl=volume control
Ol=open lid

Pc=plug cord into outlet
St=stop key
Ls=listen to sound
Lb=look into battery compartment

Ic=insert cassette
Pl=play key
Cl=close lid

Ej=eject button
Rp=record & play keys
Tk=talk into recorder

Figure 3. Behavior sequences for expert and nonexpert subjects operating the cassette tape recorder.

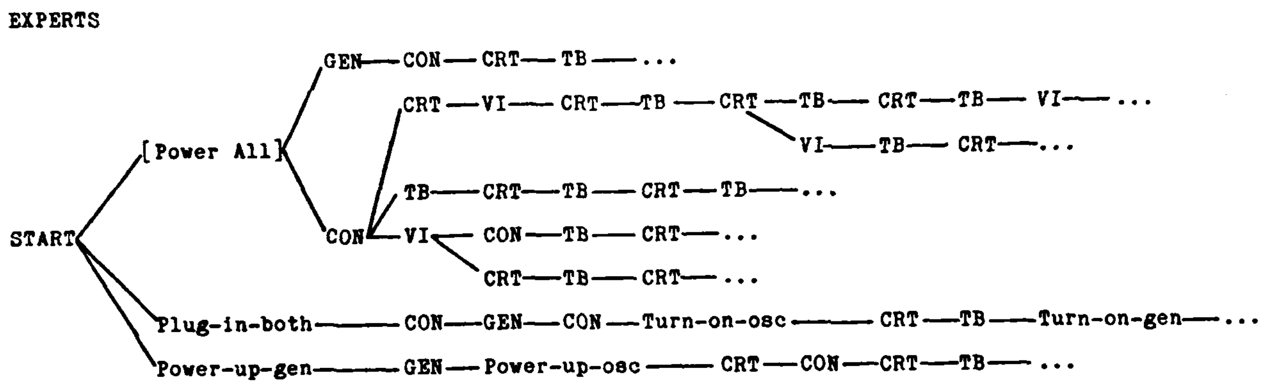


Ir=insert red lead
Cr=clip red lead to resistor
Ur=unclip red lead from resistor
Am=adjust meter zero screw
Tz=turn zero ohms knob

Ib=insert black lead
Cb=clip black lead to resistor
Ub=unclip black lead from resistor
Tc=turn center range selector
Rn=read number from meter scale

Cl=clip leads together
Ul=unclip leads
Ux=unclip both leads from resistor
Tm=turn mode selector

Figure 4. Behavior sequences for experts operating the Volt-Ohm-Milliameter.



GEN=adjust generator controls
VI=adjust vertical input controls
Power All=power up both units

CRT=adjust CRT controls
CON=make connections
Power-up=plug in and turn on

TB=adjust time base controls

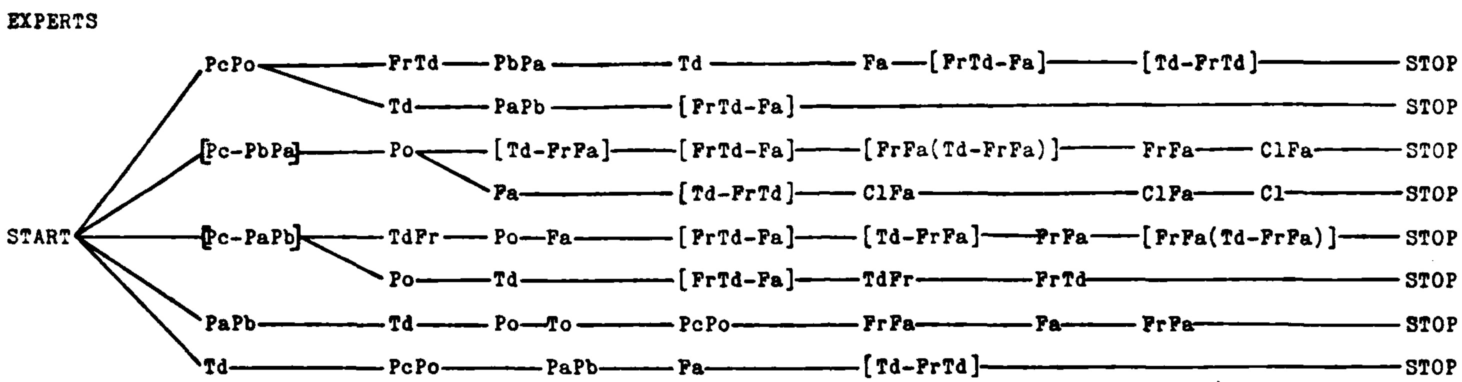
Figure 5. Highly condensed behavior sequences for experts operating the oscilloscope.

Lack of fixed procedures. The fact that on the whole there is very little stereotyped behavior seems to disconfirm the hypothesis suggested above, which is that device schema knowledge tightly specifies operating procedures for devices. However, it should be pointed out that there are some strong consistencies in at least the initial stages of operating at least some of the devices. For example, with the radio (Figure 2), all subjects plugged it in first. With the recorder, roughly half of the experts and nonexperts plugged the device in as the first step. With the oscilloscope, most of the subjects plugged in and turned on both the oscilloscope and the signal generator before going any further, but there were some subjects that performed only part of this operation before proceeding. Likewise, notice that many subjects, after performing the power-up operations, went on to connect the two devices together before proceeding any further. Finally, with the demonstrator, again most of the subjects plugged in the cord first, although some of them plug in all of the cords and connectors before turning on the device.

The VOM presents an interesting contrast, because it does not have to be plugged in and turned on. Notice that there is very little stereotypy in the sequence of activities. One might think that inserting the test leads would be the natural first step, but only two of the five subjects did this. Or one might think that adjusting the meter to zero would be a natural first step; only one of the subjects did so, although it should be noted that this is not a routine operation in the normal use of a meter of this type. Thus, it appears that there is some stereotyped behavior, but it is limited to some of the very initial stages of device operation, and concerns mainly "power-up" procedures. If people indeed follow schematic procedures, these procedures are of such a limited and varied nature that characterizing them as schemas is of little value.

How subjects operate from memory. This lack of stereotypy requires explanation. Closer examination of the task situation of operating a device from memory suggests that the expectation that device operation would show stereotyped orders is not reasonable. That is, although the devices were representatives of a very familiar type of device, such as a radio, the likelihood that an individual subject had actually had extensive practice with operating this particular make and model of device is essentially zero. To some extent, every device was a novel device to every subject. Thus, none of the actual skills of operating the device would be highly automated, because this would only be the case if one were familiar with the specific location and properties of the particular device. Thus, subjects were essentially operating these devices in a _problem-solving_ mode, instead of a memory retrieval mode. Once the problem is looked at in this light, the lack of stereotypy in the behavior becomes clear.

In any actual device, there are constraints that are imposed by the device on the order in which things are done. For example, on an oscilloscope, the intensity control must be adjusted before a trace can be seen, and the oscilloscope can not be used until



Pc=plug in power cord
Td=turn dial
To=turn power off

Po=turn power on
Pa=Plip A/B mode

Pa=plug in light A
Pr=Plip rate/phase

Pb=plug in light B
Cl=check lights

Figure 6. Behavior sequences for experts operating the phi phenomenon demonstrator.

the trace is visible. Before the intensity control can be properly adjusted, however, the oscilloscope must be turned on. Thus, for any device there are some constraints on the order of certain operations. However, even for relatively simple devices, such as a radio, these constraints in fact specify very little of the exact order of operation; many steps are independent of order given that the overall constraints are met. For example, the radio tuning can be adjusted at any time, but most usefully after the radio is audibly playing. Thus, referring to Figure 2, there are many different orders in which the expert subjects operated the controls on the radio, and there is a unique path for every subject. However, all of the subjects succeeded in operating the radio, and typically with very little wasted time or steps.

Conclusion. The best characterization of operating a piece of equipment from memory seems to be that subjects perform problem-solving by determining what constraints need to be satisfied along the way, and then operating the controls in a manner that meets the constraints and accomplishes the task, but does not necessarily follow any prescribed order. Since a major constraint is that the device be operating before it can be adjusted, there is a strong tendency for "power-up" steps to be done first. Since these data involve only a single observation on each subject in each device, it is impossible to tell whether each subject was following an individual stereotyped sequence, which seems unlikely. However, it is very clear that device operating sequences do not have a major property of schemas, namely, stereotypy of content.

The larger implication of this conclusion is that even though experts can operate even complex pieces of equipment completely from prior knowledge, they do not perform this by rote memory retrieval but rather by a very general problem-solving process. For example, the best characterization of what the experts did with the oscilloscope is that once they had it plugged in, turned on and connected with a signal generator, they made many passes over the controls making various fine adjustments in all sections of the oscilloscope until they had achieved the final desired result. Many of the operations were undoubtedly redundant from a strictly technical point of view. However, these general processes are powerful enough that the experts could operate the completely novel device, the phi phenomenon demonstrator, without any instructions, and quite often without any serious mistakes or wasted actions.

The general conclusion is that expertise does not consist of a set of canned procedures for operating different devices, but rather of a set of powerful problem-solving heuristics which can be applied to even novel devices, but which are not very efficient even with familiar devices.

SUMMARY

The introduction listed three questions that this experiment was designed to address. These concerned the instruction format, the nature of expertise effects, and the nature of the prior knowledge that people would have about electronic equipment. This experiment yielded information about each of these three questions which can be summarized as follows:

Instruction Format. Contrary to intuition, the menu format was not better overall than the step-by-step format; which format is superior depends on the user's experience. Under some conditions the specific experience with the actual device involved can be more important than the user's general expertise. If the device is familiar, the menu format helps, as would be expected, by reducing the amount of instructions that must be read. Subjects tend not to read familiar steps such as descriptions of how to power-up the equipment which everyone knows, nor do they read descriptions of procedures that are very similar to ones they have just completed. If a device is not familiar, the user can go astray, and the result may be much worse than using step-by-step instructions in terms of total completion time.

Expertise Effects. Expertise had both specific and general effects in these results. Experts were faster overall, both in the menu and the step-by-step conditions. But experience with the specific device can be as important as the general experience. The experts were more efficient than the nonexperts in terms of being able to carry out complicated physical activities. Although everybody knows certain things about electronic equipment, such as how to turn on a device, even on everyday devices the experts are more efficient and more consistent in their activities than nonexperts.

Prior knowledge of electronic devices. It was proposed that since people apparently have schema knowledge for electronic devices, that they would also have knowledge of schematic procedures for operating devices. A primary characteristic of such schematic procedures would be a high degree of stereotypicality in how the devices were operated when subjects did not choose to read instructions. This expectation was contradicted by the data; there was very little stereotyped behavior when subjects operated the devices strictly on the basis of their prior knowledge.

A more accurate assessment is based on making a distinction between what people do when they have a highly automated skill at operating a particular piece of equipment, and the ability to operate equipment in a more normal setting in which every piece of equipment is familiar, but not highly practiced. In this case, what subjects do is to engage in complicated problem-solving strategies, where the individual operating steps meet loose constraints that are imposed by the nature of the device, but do not otherwise fall into a strict stereotyped sequence. This problem-solving strategy is very robust but it is inconsistent between individuals and can be inefficient. Experts clearly have much more powerful strategies than nonexperts for operating devices on the basis only of prior knowledge, but in the case of unfamiliar equipment, their performance may actually be considerably poorer than that of nonexperts who are following strict step-by-step instructions.

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Navy

1 Robert Ahlers
Code N711
Human Factors Laboratory
NAVTRAEQUIPCEN
Orlando, FL 32813

1 Dr. Ed Aiken
Navy Personnel R&D Center
San Diego, CA 92152

1 Dr. Meryl S. Baker
Navy Personnel R&D Center
San Diego, CA 92152

1 Dr. Nick Bond
Office of Naval Research
Liaison Office, Far East
APO San Francisco, CA 96503

1 Dr. Richard Cantone
Navy Research Laboratory
Code 7510
Washington, DC 20375

1 Dr. Fred Chang
Navy Personnel R&D Center
San Diego, CA 92152

1 Dr. Stanley Collyer
Office of Naval Technology
800 N. Quincy Street
Arlington, VA 22217

1 CDR Mike Curran
Office of Naval Research
800 N. Quincy St.
Code 270
Arlington, VA 22217

1 Dr. Jude Franklin
Code 7510
Navy Research Laboratory
Washington, DC 20375

1 Dr. Jim Hollan
Code 14
Navy Personnel R & D Center
San Diego, CA 92152

1 Dr. Ed Hutchins
Navy Personnel R&D Center
San Diego, CA 92152

Navy

1 Dr. Norman J. Kerr
Chief of Naval Technical Training
Naval Air Station Memphis (75)
Millington, TN 38054

1 Dr. Peter Kincaid
Training Analysis & Evaluation Group
Dept. of the Navy
Orlando, FL 32813

1 Dr. William L. Maloy (02)
Chief of Naval Education and Training
Naval Air Station
Pensacola, FL 32508

1 Dr. Joe McLachlan
Navy Personnel R&D Center
San Diego, CA 92152

1 Dr. James McMichael
Navy PersonnelR&D Center
San Diego, CA 92152

1 Dr William Montague
NPRDC Code 13
San Diego, CA 92152

1 Technical Director
Navy Personnel R&D Center
San Diego, CA 92152

6 Commanding Officer
Naval Research Laboratory
Code 2627
Washington, DC 20390

1 Office of Naval Research
Code 433
800 N. Quincy SStreet
Arlington, VA 22217

6 Personnel & Training Research Group
Code 442PT
Office of Naval Research
Arlington, VA 22217

1 Office of the Chief of Naval Operations
Research Development & Studies Branch
OP 115
Washington, DC 20350

Navy

1 Dr. Robert G. Smith
Office of Chief of Naval Operations
OP-987H
Washington, DC 20350

1 Dr. Alfred F. Smode, Director
Training Analysis & Evaluation Group
Dept. of the Navy
Orlando, FL 32813

1 Dr. Richard Snow
Liaison Scientist
Office of Naval Research
Branch Office, London
Box 39
FPO New York, NY 09510

1 Dr. Richard Sorensen
Navy Personnel R&D Center
San Diego, CA 92152

1 Dr. Frederick Steinheiser
CNO - OP115
Navy Annex
Arlington, VA 20370

1 Dr. Thomas Sticht
Navy Personnel R&D Center
San Diego, CA 92152

1 Roger Weissinger-Baylon
Department of Administrative Sciences
Naval Postgraduate School
Monterey, CA 93940

1 Mr John H. Wolfe
Navy Personnel R&D Center
San Diego, CA 92152

Marine Corps

1 H. William Greenup
Education Advisor (E031)
Education Center, MCDEC
Quantico, VA 22134

1 Special Assistant for Marine
Corps Matters
Code 100M
Office of Naval Research
800 N. Quincy St.
Arlington, VA 22217

1 DR. A.L. SLAFKOSKY
SCIENTIFIC ADVISOR (CODE RD-1)
HQ, U.S. MARINE CORPS
WASHINGTON, DC 20380

Army

1 Technical Director
U. S. Army Research Institute for the
Behavioral and Social Sciences
5001 Eisenhower Avenue
Alexandria, VA 22333

1 Dr. Beatrice J. Farr
U. S. Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

1 Dr. Harold F. O'Neil, Jr.
Director, Training Research Lab
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

1 Commander, U.S. Army Research Institute
for the Behavioral & Social Sciences
ATTN: PERI-BR (Dr. Judith Orasanu)
5001 Eisenhower Avenue
Alexandria, VA 22333

1 Joseph Psotka, Ph.D.
ATTN: PERI-1C
Army Research Institute
5001 Eisenhower Ave.
Alexandria, VA 22333

1 Dr. Robert Sasmor
U. S. Army Research Institute for the
Behavioral and Social Sciences
5001 Eisenhower Avenue
Alexandria, VA 22333

Air Force

1 U.S. Air Force Office of Scientific
Research
Life Sciences Directorate, NL
Bolling Air Force Base
Washington, DC 20332

1 Dr. Earl A. Alluisi
HQ, AFHRL (AFSC)
Brooks AFB, TX 78235

1 Mr. Raymond E. Christal
AFHRL/MOE
Brooks AFB, TX 78235

1 Bryan Dallman
AFHRL/LRT
Lowry AFB, CO 80230

1 Dr. Alfred R. Fregly
AFOSR/NL
Bolling AFB, DC 20332

1 Dr. Genevieve Haddad
Program Manager
Life Sciences Directorate
AFOSR
Bolling AFB, DC 20332

1 Dr. T. M. Longridge
AFHRL/OTE
Williams AFB, AZ 85224

1 Dr. John Tangney
AFOSR/NL
Bolling AFB, DC 20332

1 Dr. Joseph Yasatuke
AFHRL/LRT
Lowry AFB, CO 80230

Department of Defense

12 Defense Technical Information Center
Cameron Station, Bldg 5
Alexandria, VA 22314
Attn: TC

1 Military Assistant for Training and
Personnel Technology
Office of the Under Secretary of Defens
for Research & Engineering
Room 3D129, The Pentagon
Washington, DC 20301

1 Major Jack Thorpe
DARPA
1400 Wilson Blvd.
Arlington, VA 22209

1 Dr. Robert A. Wisher
OUSDRE (ELS)
The Pentagon, Room 3D129
Washington, DC 20301

Civilian Agencies

1 Dr. Patricia A. Butler
NIE-BRN Bldg, Stop # 7
1200 19th St., NW
Washington, DC 20208

1 Dr. Susan Chipman
Learning and Development
National Institute of Education
1200 19th Street NW
Washington, DC 20208

1 Dr. Arthur Melmed
724 Brown
U. S. Dept. of Education
Washington, DC 20208

1 Dr. Andrew R. Molnar
Office of Scientific and Engineering
Personnel and Education
National Science Foundation
Washington, DC 20550

1 Dr. Everett Palmer
Mail Stop 239-3
NASA-Ames Research Center
Moffett Field, CA 94035

1 Dr. Mary Stoddard
C 10, Mail Stop B296
Los Alamos National Laboratories
Los Alamos, NM 87545

1 Chief, Psychological Reserch Branch
U. S. Coast Guard (G-P-1/2/TP42)
Washington, DC 20593

1 Dr. Frank Withrow
U. S. Office of Education
400 Maryland Ave. SW
Washington, DC 20202

1 Dr. Joseph L. Young, Director
Memory & Cognitive Processes
National Science Foundation
Washington, DC 20550

Private Sector

1 Dr. John R. Anderson
Department of Psychology
Carnegie-Mellon University
Pittsburgh, PA 15213

1 Dr. Alan Baddeley
Medical Research Council
Applied Psychology Unit
15 Chaucer Road
Cambridge CB2 2EF
ENGLAND

1 Eva L. Baker
Director
UCLA Center for the Study of Evaluation
145 Moore Hall
University of California, Los Angeles
Los Angeles, CA 90024

1 Mr. Avron Barr
Department of Computer Science
Stanford University
Stanford, CA 94305

1 Dr. Menucha Birenbaum
School of Education
Tel Aviv University
Tel Aviv, Ramat Aviv 69978
Israel

1 Dr. John Black
Yale University
Box 11A, Yale Station
New Haven, CT 06520

1 Dr. John S. Brown
XEROX Palo Alto Research Center
3333 Coyote Road
Palo Alto, CA 94304

1 Dr. Glenn Bryan
6208 Poe Road
Bethesda, MD 20817

1 Dr. Bruce Buchanan
Department of Computer Science
Stanford University
Stanford, CA 94305

1 Dr. Jaime Carbonell
Carnegie-Mellon University
Department of Psychology
Pittsburgh, PA 15213

Private Sector

1 Dr. Pat Carpenter
Department of Psychology
Carnegie-Mellon University
Pittsburgh, PA 15213

1 Dr. Micheline Chi
Learning R & D Center
University of Pittsburgh
3939 O'Hara Street
Pittsburgh, PA 15213

1 Dr. William Clancey
Department of Computer Science
Stanford University
Stanford, CA 94306

1 Dr. Michael Cole
University of California
at San Diego
Laboratory of Comparative
Human Cognition - D003A
La Jolla, CA 92093

1 Dr. Allan M. Collins
Bolt Beranek & Newman, Inc.
50 Moulton Street
Cambridge, MA 02138

1 Dr. Kenneth B. Cross
Anacapa Sciences, Inc.
P.O. Drawer Q
Santa Barbara, CA 93102

1 Dr. Emmanuel Donchin
Department of Psychology
University of Illinois
Champaign, IL 61820

1 Dr. Thomas M. Duffy
Department of English
Carnegie-Mellon University
Schenley Park
Pittsburgh, CA 15213

1 ERIC Facility-Acquisitions
4833 Rugby Avenue
Bethesda, MD 20014

1 Dr. Anders Ericsson
Department of Psychology
University of Colorado
Boulder, CO 80309

Private Sector

1 Dr. Paul Feltovich
Department of Medical Education
Southern Illinois University
School of Medicine
P.O. Box 3926
Springfield, IL 62708

1 Professor Reuven Feuerstein
HWCRI Rehov Karmon 6
Bet Hakerem
Jerusalem
Israel

1 Mr. Wallace Feurzeig
Department of Educational Technology
Bolt Beranek & Newman
10 Moulton St.
Cambridge, MA 02238

1 Dr. Dexter Fletcher
University of Oregon
Department of Computer Science
Eugene, OR 97403

1 Dr. John R. Frederiksen
Bolt Beranek & Newman
50 Moulton Street
Cambridge, MA 02138

1 Dr. Michael Genesereth
Department of Computer Science
Stanford University
Stanford, CA 94305

1 Dr. Don Gentner
Center for Human Information Processing
University of California, San Diego
La Jolla, CA 92093

1 Dr. Dedre Gentner
Bolt Beranek & Newman
10 Moulton St.
Cambridge, MA 02138

1 Dr. Robert Glaser
Learning Research & Development Center
University of Pittsburgh
3939 O'Hara Street
PITTSBURGH, PA 15260

1 Dr. Marvin D. Glock
217 Stone Hall
Cornell University
Ithaca, NY 14853

Private Sector

1 Dr. Josph Goguen
SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025

1 Dr. Daniel Gopher
Faculty of Industrial Engineering
& Management
TECHNION
Haifa 32000
ISRAEL

1 Dr. Bert Green
Johns Hopkins University
Department of Psychology
Charles & 34th Street
Baltimore, MD 21218

1 DR. JAMES G. GREENO
LRDC
UNIVERSITY OF PITTSBURGH
3939 O'HARA STREET
PITTSBURGH, PA 15213

1 Dr. Barbara Hayes-Roth
Department of Computer Science
Stanford University
Stanford, CA 95305

1 Dr. Joan I. Heller
Graduate Group in Science and
Mathematics Education
c/o School of Education
University of California
Berkeley, CA 94720

1 Dr. James R. Hoffman
Department of Psychology
University of Delaware
Newark, DE 19711

1 American Institutes for Research
1055 Thomas Jefferson St., N.W.
Washington, DC 20007

1 Glenda Greenwald, Ed.
Human Intelligence Newsletter
P. O. Box 1163
Birmingham, MI 48012

1 Dr. Earl Hunt
Dept. of Psychology
University of Washington
Seattle, WA 98105

Private Sector

1 Robin Jeffries
Computer Research Center
Hewlett-Packard Laboratories
1501 Page Mill Road
Palo Alto, CA 94304

1 Dr. Marcel Just
Department of Psychology
Carnegie-Mellon University
Pittsburgh, PA 15213

1 Dr. Walter Kintsch
Department of Psychology
University of Colorado
Boulder, CO 80302

1 Dr. David Klahr
Department of Psychology
Carnegie-Mellon University
Schenley Park
Pittsburgh, PA 15213

1 Dr. Stephen Kosslyn
1236 William James Hall
33 Kirkland St.
Cambridge, MA 02138

1 Dr. Pat Langley
The Robotics Institute
Carnegie-Mellon University
Pittsburgh, PA 15213

1 Dr. Jill Larkin
Department of Psychology
Carnegie Mellon University
Pittsburgh, PA 15213

1 Dr. Alan Lesgold
Learning R&D Center
University of Pittsburgh
3939 O'Hara Street
Pittsburgh, PA 15260

1 Dr. Jim Levin
University of California
at San Diego
Laboratory fof Comparative
Human Cognition - D003A
La Jolla, CA 92093

Private Sector

1 Dr. Michael Levine
Department of Educational Psychology
210 Education Bldg.
University of Illinois
Champaign, IL 61801

1 Dr. Marcia C. Linn
Lawrence Hall of Science
University of California
Berkeley, CA 94720

1 Dr. Don Lyon
AFHRL/OT (UDRI)
Williams AFB, AZ 85225

1 Dr. Jay McClelland
Department of Psychology
MIT
Cambridge, MA 02139

1 Dr. James R. Miller
Computer*Thought Corporation
1721 West Plano Highway
Plano, TX 75075

1 Dr. Mark Miller
Computer*Thought Corporation
1721 West Plano Parkway
Plano, TX 75075

1 Dr. Tom Moran
Xerox PARC
3333 Coyote Hill Road
Palo Alto, CA 94304

1 Dr. Allen Munro
Behavioral Technology Laboratories
1845 Elena Ave., Fourth Floor
Redondo Beach, CA 90277

1 Dr. Donald A Norman
Cognitive Science, C-015
Univ. of California, San Diego
La Jolla, CA 92093

1 Dr. Jesse Orlansky
Institute for Defense Analyses
1801 N. Beauregard St.
Alexandria, VA 22311

Private Sector

1 Dr. Nancy Pennington
University of Chicago
Graduate School of Business
1101 E. 58th St.
Chicago, IL 60637

1 DR. PETER POLSON
DEPT. OF PSYCHOLOGY
UNIVERSITY OF COLORADO
BOULDER, CO 80309

1 Dr. Mike Posner
Department of Psychology
University of Oregon
Eugene, OR 97403

1 Dr. Lynn Reder
Department of Psychology
Carnegie-Mellon University
Schenley Park
Pittsburgh, PA 15213

1 Dr. Fred Reif
Physics Department
University of California
Berkeley, CA 94720

1 Dr. Lauren Resnick
LRDC
University of Pittsburgh
3939 O'Hara Street
Pittsburgh, PA 1521

1 Dr. Jeff Richardson
Denver Research Institute
University of Denver
Denver, CO 80208

1 Mary S. Riley
Program in Cognitive Science
Center for Human Information Processing
University of California, San Diego
La Jolla, CA 92093

1 Dr. Andrew M. Rose
American Institutes for Research
1055 Thomas Jefferson St. NW
Washington, DC 20007

1 Dr. Ernst Z. Rothkopf
Bell Laboratories
Murray Hill, NJ 07974

Private Sector

1 Dr. William B. Rouse
Georgia Institute of Technology
School of Industrial & Systems
Engineering
Atlanta, GA 30332

1 Dr. David Rumelhart
Center for Human Information Processing
Univ. of California, San Diego
La Jolla, CA 92093

1 Dr. Michael J. Samet
Perceptronics, Inc
6271 Variel Avenue
Woodland Hills, CA 91364

1 Dr. Roger Schank
Yale University
Department of Computer Science
P.O. Box 2158
New Haven, CT 06520

1 Dr. Walter Schneider
Psychology Department
603 E. Daniel
Champaign, IL 61820

1 Dr. Alan Schoenfeld
Mathematics and Education
The University of Rochester
Rochester, NY 14627

1 Mr. Colin Sheppard
Applied Psychology Unit
Admiralty Marine Technology Est.
Teddington, Middlesex
United Kingdom

1 Dr. H. Wallace Sinaiko
Program Director
Manpower Research and Advisory Services
Smithsonian Institution
801 North Pitt Street
Alexandria, VA 22314

1 Dr. Edward E. Smith
Bolt Beranek & Newman, Inc.
50 Moulton Street
Cambridge, MA 02138

Private Sector

1 Dr. Eliott Soloway
Yale University
Department of Computer Science
P.O. Box 2158
New Haven, CT 06520

1 Dr. Kathryn T. Spoehr
Psychology Department
Brown University
Providence, RI 02912

1 Dr. Robert Sternberg
Dept. of Psychology
Yale University
Box 11A, Yale Station
New Haven, CT 06520

1 Dr. Albert Stevens
Bolt Beranek & Newman, Inc.
10 Moulton St.
Cambridge, MA 02238

1 David E. Stone, Ph.D.
Hazeltine Corporation
7680 Old Springhouse Road
McLean, VA 22102

1 Dr. Kikumi Tatsuoka
Computer Based Education Research Lab
252 Engineering Research Laboratory
Urbana, IL 61801

1 Dr. Maurice Tatsuoka
220 Education Bldg
1310 S. Sixth St.
Champaign, IL 61820

1 Dr. Perry W. Thorndyke
Perceptronics, Inc.
545 Middlefield Road, Suite 140
Menlo Park, CA 94025

1 Dr. Douglas Towne
Univ. of So. California
Behavioral Technology Labs
1845 S. Elena Ave.
Redondo Beach, CA 90277

1 Dr. Kurt Van Lehn
Xerox PARC
3333 Coyote Hill Road
Palo Alto, CA 94304

Private Sector

1 Dr. Keith T. Wescourt
Perceptronics, Inc.
545 Middlefield Road, Suite 140
Menlo Park, CA 94025

1 William B. Whitten
Bell Laboratories
2D-610
Holmdel, NJ 07733

1 Dr. Thomas Wickens
Department of Psychology
Franz Hall
University of California
405 Hilgarde Avenue
Los Angeles, CA 90024

1 Dr. Mike Williams
IntelliGenetics
124 University Avenue
Palo Alto, CA 94301

1 Dr. Joseph Wohl
Alphatech, Inc.
2 Burlington Executive Center
111 Middlesex Turnpike
Burlington, MA 01803