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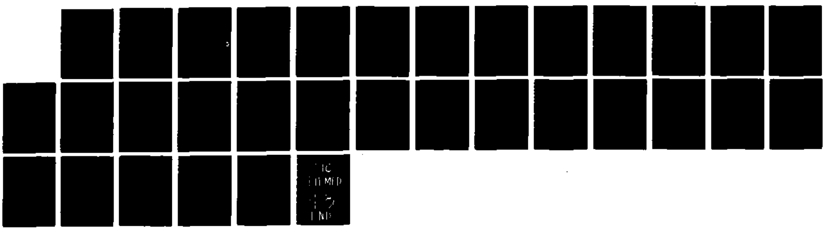

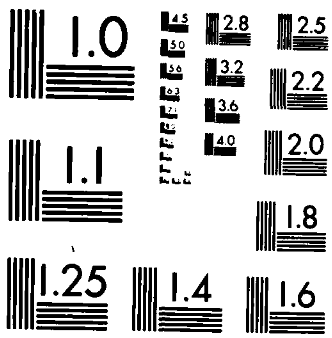

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This work was supported by Contract No.: N0014-83-C-0537, Work Unit No. NR 197-078 from the Engineering Psychology Program, Office of Naval Research, to the PAR Technology Corporation. The views and conclusions expressed in this paper are those of the authors and not those of the above agency or its representatives.

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3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) HUMAN FACTORS IN RULE-BASED SYSTEMS: FINAL REPORT	5. TYPE OF REPORT & PERIOD COVERED
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Paul E. Lehner; Debra Zirk; Richard B. Hall; Leonard Adelman	8. CONTRACT OR GRANT NUMBER(s) N00014-83-C-0537
9. PERFORMING ORGANIZATION NAME AND ADDRESS PAR TECHNOLOGY CORPORATION 7926 JoneS Branch Drive McLean, VA 22102	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR197-078
11. CONTROLLING OFFICE NAME AND ADDRESS OFFICE OF NAVAL RESEARCH 800 N. Quincy Street Arlington, VA 22217	12. REPORT DATE October 14, 1985
	13. NUMBER OF PAGES 21
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report) UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Expert Systems, Human Factors, Man/Machine Interface, Mental Models, Cognitive Consistency

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report summarizes several experiments investigating the impact of mental models and cognitive consistency on user/expert system interaction. Results indicate that user/expert system combined problem solving performance significantly improves if the user has a good mental model of expert system processes. Furthermore, 'cognitive consistency' between the user and system problem solving procedures only degrades performance in situations where users

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20. Abstract (continued)

do not have a good mental model. Some practical implications of this research is discussed.

Keywords: man-machine interface

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INTRODUCTION

This report summarizes the research performed under Contract No.: N00014-83-C-0537 to the Office of Naval Research, entitled "Human Factors in Rule-Based Systems." The period of performance of this effort was August 15, 1985, to September 30, 1985. As indicated in the original proposal, this research effort was oriented toward supporting two long-term interrelated goals (1) to advance a general theory of the cognitive psychology of user interactions with rule-based systems and (2) to recommmend, based on the general thoery, design principles for the user engineering of expert systems. A general discussion of the work performed during this effort, and the results therefrom, is presented below.

BACKGROUND AND PROBLEM SELECTION

Most military applications of expert system technology involve building expert systems that are, from a psychological person/machine interface perspective, very different from traditional systems, such as PROSPECTOR and MYCIN, that were developed in laboratory settings. In particular, as documented in Lehner (1984), most military applications of expert system technology differ from the traditional systems in that:

(1) The traditional systems addressed problem domains with a well-established, well-documented, and static knowledge base. Military applications tend to involve ill-specified knowledge bases, where human experts differ considerably in their opinions.

(2) In the traditional systems, it was sufficient to model the system after one good human expert. In many military applications, the system must somehow merge the expertise of multiple human experts with the differing areas of expertise.

(3) In the traditional systems, the assumed user community was not very diverse. Users of medical diagnosis programs were likely to have some type of medical degree (M.D., R.N., etc.). Users of systems such as PROSPECTOR were assumed to be people with a significant background in geology. In many military applications, on the other hand, the level and type of experience and training of users will vary considerably.

(4) Finally, the traditional systems were stand alone. The user entered all problem specific data. As a result, it could be assumed that users were already familiar with all data available to solving the problem at hand. Many military applications, on the other hand, require that the expert system be embedded within a larger 'background' system. As a result, it must be assumed that users will not be, a priori, familiar with the specifics of the problem being addressed. Indeed, the user may not even know a problem exists until the expert system has already analyzed data, obtained from the background system, and generated its conclusions and recommendations.

Given (1) through (4) above, it seemed reasonable to characterize the general user/expert system setting as a situation where two expert problem solvers are trying to cooperatively solve a common decision problem despite the fact that these two experts may use different decision processes, heuristics and data to solve the common problem. For users of military expert systems, these differences will often be very pronounced. This is not a very encouraging setting, particularly if one accepts the conventional wisdom on user/expert system interaction that says the more an expert system mimics a user's problem solving style and heuristics, the better user/system cooperative problem solving performance will be. Indeed, systems that are inconsistent with the user's approach tend to be flatly rejected by users (Clancey, 1984).

The problem we selected to address was to discover the conditions under which user/expert system performance would remain high despite significant differences between the approaches of the two problem solvers. This naturally leads to the more general research issue of discovering, in general, what the primary drivers were of effective user/expert system interaction. Furthermore, we wanted to focus on mediating variables that could easily generalize to any user/machine environment that involved an 'intelligent' machine. Finally, our professional interests lead us to focus on cognitive issues rather than on perceptual/display design issues. In addition, it was felt that if one could satisfactorally address the cognitive issues, then it should be possible to derive a number of specific implications for display design.

Given the above orientation, the next question then became one of identifying the cognitive dimensions that need to be considered. A literature review suggested two basic dimensions

(1) human cognitions about the problem domain, and

(2) human cognitions about the machine's cognitions about the problem domain.

This lead us to postulate that two of the key drivers of the nature of a user/expert system interactions would to a significant extent be

(1) the degree to which the person's and machine's cognitions about a problem overlapped (the <u>cognitive consistency</u> dimension), and

(2) how well the user understood the machine's cognitions about a problem domain even when they differed significantly from the user's (the <u>mental model</u> dimension).

It was further postulated that if the user had a good mental model of how the machine goes about solving the problem, the user should still be able to effectively interact with the machine even if the machine solves the problem in a manner different than the user.

Of course, the value of interacting with the machine will depend on exactly how the user and machine's cognitions about a problem differ. If the person and machine come up with different conclusions, and the machine has access to relevant data the user didn't know about, then interacting with the machine to retrieve that data is clearly very valuable. On the other hand, if the person and machine generated different conclusions because the person and machine used different heuristics, but the same data, then the value of being able to 'trace' the machines logic will depend on how well the user can incorporate the machine's cognitions into his or her own reasoning about the problem. The experiments discussed below address these issues

SUMMARY OF EXPERIMENTS PERFORMED

The experiments performed under this project [see Lehner et al., (1984); Lehner & Zirk, (1985); Hall, (1985)] were oriented toward testing the general hypothesis that a good mental model of an expert system's cognitions would lead to good user/expert system performance even when the user had very different cognitions than the expert system in solving the problem. Furthermore, it was hypothesized that when the user did not have a good mental model of the expert system's processing, the conventional wisdom, suggesting that performance improves as the overlap between the person's and machine's cognitions increase, would hold true.

The traditional procedure for the first three experiments used a generic expert system development package (PAR's ERS software) that is similar in many respects to the classical PROSPECTOR system. In particular, the user interface of this system is fairly typical of systems such as PROSPECTOR. Using the expert system development package, a small rule base was built for selecting from among alternative stocks under various stock market conditions. In all three experiments subjects were split into two different types of decision processes (based on the procedures they were taught for solving the problem manually): a goal-driven process that was similar to the stock market expert system's, and a data driven process that was very different than the stock market expert system's procedures. Both processes, if properly applied, generated the same answers. In addition, a 'good mental model' and a 'poor mental model' condition was created. The good mental model students were given two pages of typed text (double spaced) that explained that the expert system used rules, and that these rules could be conceptually organized into inference networks. In the poor mental model condition subjects received only a short general descriptions as to how the expert system solved a stock market decision problem.

In experiment 1, both the subject and expert system had isomorphic decision rules (i.e., they would come up with the same answers), but there was inconsistency in the data sets. The expert system had access to data the subjects did not initially have, while the data the subjects did have was somewhat more accurate than the expert system's. Under this condition, subjects needed to interact with the expert system to get all relevant data, but the expert system did not necessarily generate the correct answers.

The primary results for experiment 1 are shown below. The cell values indicate the percent of problems users answered correctly.

		User's Decision Process	
		Consistent with expert system	Inconsistent with expert system
Quality of User's Mental Model	Good	58%	83%
	Poor	50%	25%

Clearly, when the subjects and the expert system used similar decision processes, mental model had little impact. On the other hand, when the subjects and expert system employed different decision processes, the impact of a mental model was dramatic.

Analyzing the results of the first experiment, we concluded two things: (1) the data-driven procedure was easier for subjects to employ manually than the goal driven procedure, and (2) the primary driver of the 83%-25% difference between the good and poor mental model subjects under the process inconsistent condition was that subjects with the good mental model condition were able to effectively manipulate the expert system to gain access to the missing data while the poor mental model subjects often failed to extract the missing data in time to solve the problem. The poor mental model subjects did not need to 'manipulate' the expert system to obtain necessary data.

Experiment 2 empirically tested (2) above. In this experiment the good mental model/inconsistent and poor mental model/inconsistent conditions were replicated with the single exception that subjects in the latter condition had an additional command that would give them an immediate display of all the relevant data the machine had available. The primary result is shown below.

		User's Decision Processes
		Inconsistent with expert system
Quality of User's	Good	78%
Mental Model	Poor	69%

We felt our hypothesis was supported.

Summarizing these two experiments, it appears that a having a good mental model allowed users to be effective operators of the expert system even when the user and expert system employed inconsistent decision processes. As a result, subjects with a good mental model were able to access necessary data, while subjects with a poor mental model often failed to do so. It should be noted however that in these experiments subjects had little need to actually trace the expert system's reasoning to get assistance, they simply needed to find a sequence of commands that would get them to the missing data. Consequently, it was not clear the extent to which a good mental model helped subjects actually understand how the system generated a recommendation.

Experiment 3 addressed this latter issue. In particular, we wanted to see the extent to which a good mental model helped subjects to isolate 'errors' in an expert system rule set. In this experiment the four cells in experiment 1 were replicated with the following changes:

(1) both the subject and expert system had the same data,

(2) some of the parameter values in the rules were modified, leading to erroneous conclusions,

(3) for each problem, subjects were given the correct answer based on the manual procedures they were taught to use, and

(4) the subjects task was to find the erroneous parameter value(s) and rule(s) in the expert system.

The results of this experiment are shown below. Cell values indicate percent of problems where subjects isolated the erroneous rules

	User's Decision Process	
Quality of User's Mental Model	Consistent with expert system	Inconsistent with expert system
Good	68%	65%
Poor	45%	30%

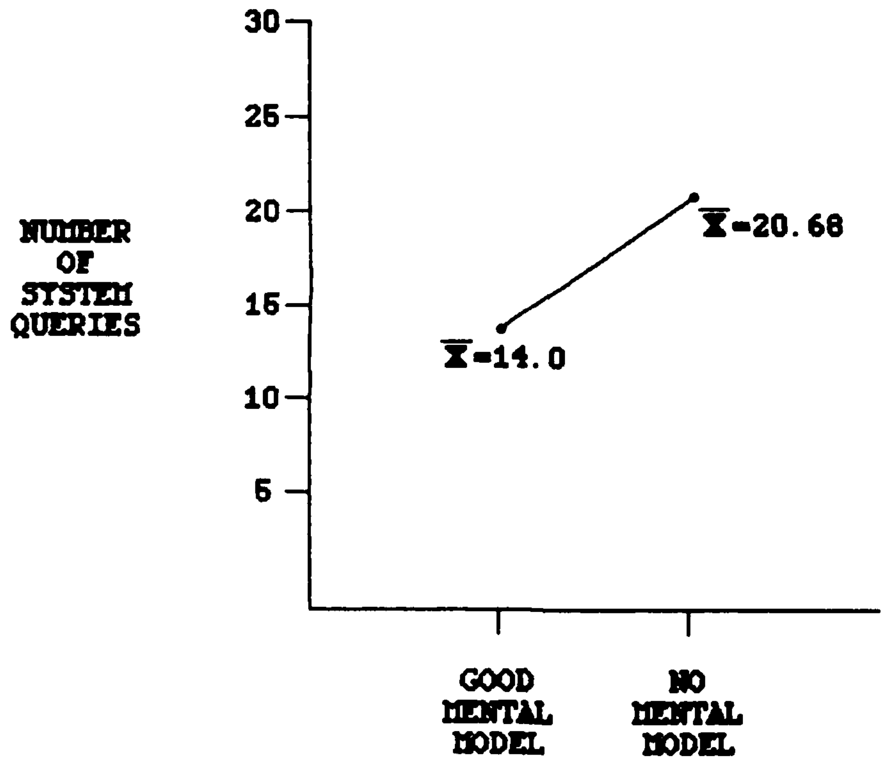
As with experiment 1, cognitive consistency had a positive impact only when subjects had a poor mental model.

Finally, in an attempt to generalize the results of the above experiments, a fourth experiment was performed using a 'real world', complex expert system, rather than the artificial stock market problem used in the previous experiments. Specifically, the Stanford University MYCIN system was used as the testbed. Subjects (third- and fourth-year medical students) were given a summary MYCIN recommendation for an individual test case, and were required to exercise MYCIN to determine exactly how it generated its recommendation. (See Hall, 1985, for details.) In this experiment, the subjects were either in a poor mental model or good mental model condition, using essentially the same manipulation of mental model used in the previous experiments. The primary dependent variable was the number of individual MYCIN rules that subjects examined before finding the specific, high-level rule that resulted in the MYCIN recommendation.

Preliminary results for this experiment are shown on the following page. Unfortunately, because of limited subject availability, only three subjects per group were run by project termination. Even with only six subjects however, a t-test comparison of the two groups was 'significant' at the .1 level (one-tailed test). We expect to collect some additional data in the near future.

DISCUSSION AND CONCLUSION

The basic conclusions for these experiments appears to be that in a cooperative human/intelligent machine problem solving setting, where the human and machine employ different problem solving procedures, it



Performance as measured by number of system queries by mental model condition is generally essential that the user have an accurate model of how that machine operates. Even for relatively simple decision problems, such as the one used in these experiments, a poor mental model leads to anywhere from a 30% to 60% drop in performance. For military expert system applications the need for a good mental model may be particularly important. As previously noted, users of military expert systems are likely to be significantly inconsistent from the expert system in both the problem specific data they are initially aware of and the domain specific heuristics utilized in problem solving. The user/expert interface system interaction in these systems is a situation that naturally reflects a great deal of cognitive inconsistency. As a result, creating an accurate mental model may be an essential ingredient for the successful transfer of military expert systems to operational use.

Regarding the completeness of the above research, it should be recognized that these experiments operationalized cognitive consistency as the match between the user's and the expert system's procedures. Other dimensions of cognitive consistency need to be examined. Furthermore, a node description command was the only type of explanation a user could receive in this study. This was chosen primarily because of the imposed time constraint and the nature of the task setting. Other explanation capabilities should be examined, including a rule-trace or presentation of the sytem's intermediate hypotheses.

Finally, it should be noted that the mental model manipulation was unitary. No attempt was made to separately test possible components of a mental model. Experimental materials were prepared for Experiment 4 that decomposed mental model into several, independently manipulatible parts. However, limited subject availability made it impossible to have more than one good mental model condition. In defense of our unitary mental model manipulation, however, it should also be noted that despite a considerable amount of interest in the concept of mental and cognitive models, empirical research has not demonstrated the generality of the impact of the mental model on user/machine interaction (Rouse, 1985). As a result, we feel that the key contribution of the research discussed above has been to empirically establish 'mental model' as a key driver in the specific context of user/expert system interaction.

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APPENDIX A

LIST OF REPORTS, PAPERS, AND PRESENTATIONS FROM THIS EFFORT

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