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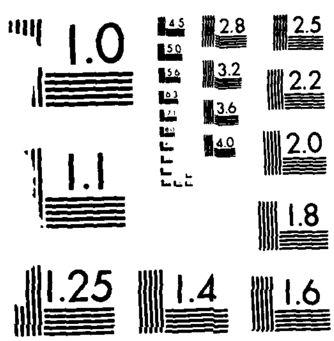

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MENTAL MODELS AND PROBLEM SOLVING WITH A KNOWLEDGE-BASED EXPERT SYSTEM

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MENTAL MODELS AND PROBLEM SOLVING WITH A KNOWLEDGE-BASED EXPERT SYSTEM

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Previous research in the area of user/expert system interaction has shown that the quality of problem solving with a general expert system (ES) is associated with mental model, a user's conceptual understanding of the basic principle of an ES's problem sovling process. The current paper describes an experiment with MYCIN, a medical knowledge-based expert system, that lends additional support to the link between problem solving quality and mental model.

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INTRODUCTION

The proliferation of the scientific literature in recent years has encouraged the application of computer technology to such traditional human endeavors as information analysis and problem solving. Within the biological sciences, for example, the knowledge base reportedly doubles every five years (Ziman, 1980). As a result, domain experts have become increasingly inundated with new information.

Computer technology, particularly the field of artificial intelligence, has been shown to hold considerable promise for dealing with this problem. This has been especially true in the realm of medicine where literature proliferation has become an immense problem for the line physician. Consequently, it was appropriate that one of the first successful knowledge based expert systems, MYCIN, was developed for specialized medical diagnosis and treatment (Shortliffe, 1976).

Prerequisite for effective use of intelligent machines such as MYCIN is the design of user/machine interfaces that encourage user acceptance and that optimize user/machine performance. Accordingly, this paper describes empirical research investigating the cognitive psychology of user interactions with the MYCIN system. This research was performed in the context of a more general research program that focused on advancing a general understanding of the psychology of user interactions with intelligent machines and that also endeavored to generate design principles that could lead to optimal user engineering of future expert systems.

The central theory of the current study is that a user's ability to solve problems in conjunction with an intelligent system depends upon the user's mental model of that system's operating processes. Three experiments reported in a previous study (Lehner & Zirk, 1985), strongly supported this idea. In the Lehner and Zirk experiments, problem solving with a generic expert system, ERS, Embedded Rule Based System (Barth, 1984) using a stock market game domain was shown to be significantly enhanced by an accurate mental model of system operation.

Although this mental model concept appeared to be supported by the previous experiments, it acquired support within the confines of an artificial domain whereas the present study examined the impact of mental model on problem solving performance within the domain of real world medical consultations.

In the case of expert systems like MYCIN, mental model can be understood in terms of two general categories: machine understanding and content understanding. For instance, machine understanding refers to recognition that (1) knowledge is encoded in rules, (2) rules tend to be organized as inference networks, and (3) that the problem solving processes are goal driven, (i.e., MYCIN selects a potential diagnosis and then tests symptomology against medical laboratory test results to confirm or disprove it.) Content understanding refers to the extent to which the user knows the specific heuristics that have been encoded into an expert system. In the present study, the impact of mental model on the problem solving performance of domain experts was investigated through the presentation of mental model - specific instructional material in terms of machine understanding.

METHOD

Subjects

Six second and third year medical students from Howard Medical School and the George Washington University Medical School participated as paid participants in the current study. The mean age was 26 with a range of 24 to 30 years. None of the participants had prior experience with rule-based systems or computer aided problem solving tasks.

Materials

A rule-based expert system, MYCIN (Shortliffe, 1974), was used as the intelligent interface testbed for the current study. MYCIN is a backward chaining heuristic medical consultation system that provides advice to physicians on the diagnosis of bacterial infections and appropriate drug therapy. The data base in this case is the physician himself providing information in response to questions generated by the program. The Mycin program contains several hundred rules with attached certainty factors of the form "if premise then action" within which, antibiotic treatment knowledge is encoded and against which the patient's state and initial laboratory findings are tested. Rules with matching conditions are subsequently executed and the final result is a set of rank ordered therapy recommendations.

The MYCIN system consists of three interrelated programs. An overall diagram of MYCIN and the relationship between the component programs is shown in Figure 1.

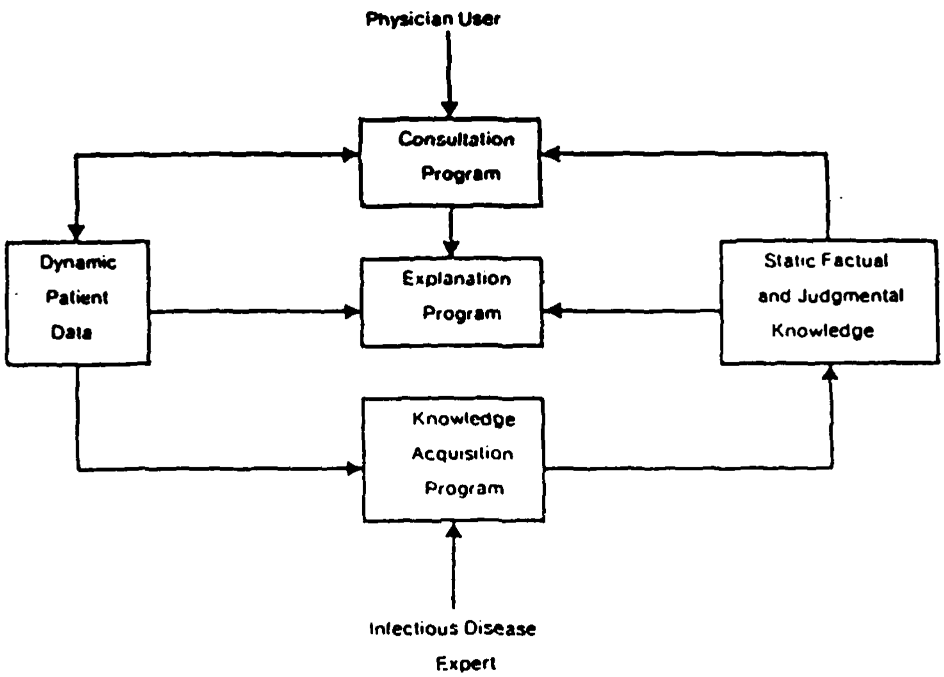

Physician User
Consultation Program
Dynamic Patient Data
Explanation Program
Static Factual and Judgmental Knowledge
Knowledge Acquisition Program
Infectious Disease Expert

Figure 1

The Consultation program serves as the core of the system; it interacts with the physician to obtain information about the patient, generating diagnoses and therapy recommendations. The Explanation program provides explanations and justifications for the program's actions while the Knowledge-Acquisition program allows domain experts to update the system's knowledge base.

MYCIN is written in Interlisp-D and currently runs on Digital Equipment Corporation DEC System-20 computer systems using either the VMS or UNIX operating systems.

For the present study, an APPLE IIE computer was remotely linked to MYCIN at Stanford Medical Center's SUMEX-AIM computer via TYMNET.

Experimental Design

The two levels of the independent variable were (1) mental model and (2) no mental model. The dependant measure was task performance as measured by the number of system queries used for each of the four problems. Subjects in the mental model condition received as part of their instructions a written and illustrated description of rules, inference networks and backward chaining procedures. This section described the structure of a general inference network, explained how the MYCIN system identified goals, intermediate hypotheses, and data items, and chained up and down the network to obtain degree of certainty values for each goal. Included in this section was a pictorial display of an inference net and a simple example of its operation. By working through this section, the user presumably developed a mental model of how the expert system solved problems. Subjects in the no mental model condition were only afforded a cursory explanation concerning machine knowledge.

Test Bed Domain

The experimental domain was a medical consultation system, MYCIN. Task problems were constructed by creating four completed consultation sessions for which a number of heuristics were employed by MYCIN to generate diagnostic heirarchies and their accompanying treatment recommendations (a sample MYCIN consultation is contained in appendix A). Thus, for each of the four problem's set of rules, there was only one rule responsible for the primary diagnosis and it was that rule the subject was instructed to find.

Procedure

Subsequent to reading a description of the experiment, subjects received the instruction booklet pretaining to their particular mental model condition assignment. These instructions specified the objectives, procedures, and requirements of the problem solving task. Subjects were seated at a table directly in front of the terminal with ample space to arrange their individual work sheets. Upon completion of the experimental booklet, the subjects were afforded a walk-through practice consultation with MYCIN and shown how to access the rules which had been used to generate the system's theraputic recommendations.

Performance Measures

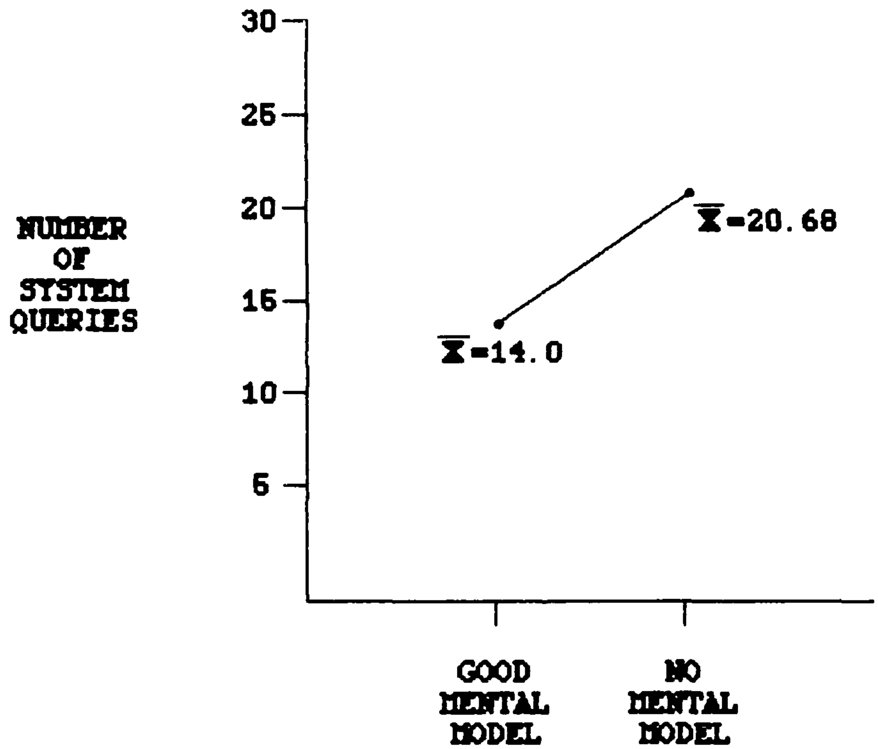
For each of four consultation problems, subjects were given a printout of a previous consultative session and a sequential list of the rules MYCIN used to reach its diagnostic and theraputic conclusions. The subjects were then instructed to interact with the MYCIN system in order to examine those rules in any order that they saw fit until they had isolated the particular rule responsible for each of the four predetermined primary diagnoses. The number of "rule" commands was recorded for each of the four problems for each subject.

A second performance measure was the ten item subjective questionaire. Subjects indicated on a ten point scale from 0 ("very strongly disagree") to 10 ("very strongly agree") their agreement with statements addressing (1) the understanding of MYCIN's operating procedures, (2) the ease of system use, (3) the confidence of final user decisions, and (4), the adequacy of the time allotment.

A second questionaire was also employed which was designed to determine which components of the mental model (in terms of instruction booklet sections which compartmentalized the concepts of rules, inference networks, and backward chaining procedures) were of most value to the participants in understanding and performing their tasks.

PRELIMINARY RESULTS

Due to difficulty in securing the participation of medical students (whose intensive training and time consuming professional responsibilities precluded easy accessability), only six subjects were actually recruited for the current study. However, performance differences were observed between the two mental model conditions. The beneficial impact of an accurate mental model on the problem solving tasks in terms of system queries is exemplified in Figure 2 by the mean scores of the two experimental groups.



Performance as measured by number of system queries by mental model condition

Figure 2

In addition to the mean differences, a T-test revealed significant differences in user performance between the two mental model conditions in terms of their use of the "rule" command $T(4)=1.94$, $.1>p>.05$,lt,sig.

Further data analysis was performed by evaluating subject's responses to the 10-item questionaire. Users receiving accurate mental models reported greater "understanding of the system's operating procedures", than did those in the no mental model group with means of 7.3 and 5.4 respectively. Reports of "ease of system use" followed the predicted pattern, the means being 7.0, and 6.5. There was no difference between the two groups in terms of "confidence of final user decisions" and "time allotment adequacy".

Responses to the second questionaire concerning the task relevance of the instructional materials revealed that their knowledge of rules, inference networks, and backward chaining processes had been the most helpful in terms of subsequent task performance. On the other hand, the no mental model group felt that the sample consultation had been the most helpful to them in terms of their task performance.

DISCUSSION

In general, the preliminary results of this study seem to agree with the basic theory that the quality of user/expert system problem solving is driven to a large degree by the user's mental model of the expert system's problem solving procedures. Highest problem solving performance was achieved by subjects having a good mental model, i.e., those having an understanding of the system's use of rules, inference networks and backward chaining procedures. The basic explanation for this is that a user with an accurate mental model is well suited to interact with an expert system for which he or she has a conceptual grasp.

Future research efforts should continue to focus on user/intelligent machine interaction using "real-world" systems such as MYCIN. The information gleaned from such efforts are likely to contribute toward the development of a theoretical base of user-expert system interaction which in turn would permit the design of more optimal, hence user acceptable, user/intelligent machine interfaces.

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APPENDIX A

SAMPLE MYCIN CONSULTATION

13-Aug-85 10:00:45

```
--------PATIENT-321--------
1) Patient's name:
** PT321
2) Age:
** 3 YEARS
3) Sex:
** FEMALE
4) Race:
** CAUCASIAN
5) Are there any cultures for Pt321 which may be related to the
   present illness, and from which organisms have been grown
   successfully in the microbiology laboratory?
** NO
6) Are there any pending cultures for Pt321?
** YES

   --------CULTURE-1--------
   7) From what site was the specimen for CULTURE-1 taken?
   ** CSF
   8) Please give the date and time when the pending csf culture
      (CULTURE-1) was obtained. (mo/da/yr time)
   ** 17-Mar-76 12:02PM
   9) Was a smear examined at the time that the specimen for the
      pending csf culture (CULTURE-1) was obtained?
   ** YES
   10) Were any organisms seen on the smear of the specimen
       submitted as the pending csf culture (CULTURE-1)?
   ** YES

      --------ORGANISM-1--------
      11) The stain (Gram, India ink, or Ziehl-Neelsen acid-fast)
          of ORGANISM-1:
      ** GRAMNEG
      12) Is ORGANISM-1 a rod or coccus (etc.):
      ** ROD
      13) What is the form of the individual organisms (e.g.
          Lancet-shaped for cocci, fusiform for rods, etc.)?
      ** UNKNOWN
   14) Any other organisms noted on the smear?
   ** NO
15) Are there any other pending cultures?
** NO
16) Have there been negative (as opposed to pending) cultures
    obtained from Pt321 which may be relevant to the present
    illness?
** NO
17) Do you suspect Pt321 may have an infection at a site from
    which you have not obtained culture specimens?
** NO
18) Is Pt321 currently receiving therapy with any antimicrobial
    agent?
** NO
19) During the present illness, has Pt321 been treated with an
    antimicrobial agent which is no longer being administered?
** NO
20) Has Pt321 recently had symptoms of persistent headache or
    other abnormal neurologic symptoms (dizziness, lethargy,
    etc.)?
** YES
21) Has Pt321 recently had objective evidence of abnormal
    neurologic signs (nuchal rigidity, coma, seizures, etc.)
    documented by physician observation or examination?
```

```
** YES
The CSF cultures will be considered to be associated with MENINGITIS.
   22) Please give the date on which clinical evidence (symptoms,
       signs, or laboratory tests) of the meningitis first appeared.
   ** 17-Mar-76 9:02PM
Although all of the CSF cultures were obtained before the clinical
   evidence of MENINGITIS began, I will consider for therapy those
   that were obtained within 48 hours of the onset.
   23) Is the meningitis a hospital-acquired infection?
   ** NO
   24) Has Pt321 had any injury or insult to, or defect in the
       central-nervous-system (excluding neurosurgery)?
   ** UNKNOWN
   25) On a scale of 0 to 4, where higher numbers indicate increasing
       severity, how would you rate Pt321's degree of sickness?
   ** 4
   26) Is Pt321 febrile?
   ** YES
   27) Do you know the results of a recent CBC of Pt321?
   ** YES
   28) What was Pt321's peripheral white count (in thousands)?
   ** 5.6
   29) Percent of WBC's which were PMN's:
   ** 79
   30) Percent of the peripheral WBC's which are immature forms:
   ** 12
   31) Is Pt321 a compromised host (e.g. alcoholic, sickle-cell-
       disease, immunosuppressed)?
   ** NO
[Considering organisms (other than those isolated from cultures)
which might be present...]
   32) Does Pt321 have an abnormal chest X-ray?
   ** NO
   33) Does Pt321 have one or more of the following risk factors for
       tb: a) positive intermediate strength PPD, b) history of close
       contact with a person with active tb, c) a household member
       with a past history of active tb, d) apical scarring on chest
       xray, e) history of granulomas on biopsy of liver, lymph node,
       or other organs.?
   ** NO
   34) For how many days has Pt321 had abnormal neurologic signs?
   ** 9.6 HOURS
   35) For how many days has Pt321 had neurologic symptoms?
   ** 12 HOURS
   36) Has Pt321 had recent evidence of tender or enlarged salivary
       glands?
   ** NO
   37) Has Pt321 been exposed to any contagious disease recently
       (e.g. meningococcal disease, mumps) ?
   ** UNKNOWN
   38) Does Pt321 have any cutaneous lesions or rash on physical
       examination?
   ** NO
   39) What is the protein value (mg/100cc) in the CSF?
   ** 326
   40) What is the total WBC count of the CSF?
   ** 1000
   41) What percent of the WBCs in the CSF were polys?
   ** 100
   42) What is the glucose value (milligrams percent) in the CSF?
   ** 113
   43) What is the simultaneous blood glucose?
   ** 220
   44) Does Pt321 have evidence of ocular nerve dysfunction?
   ** NO
```

```
45) Has Pt321 ever undergone any type of surgery?
** UNKNOWN
46) Does Pt321 live in a crowded environment?
** NO
47) Is Pt321's clinical history consistent with EPIGLOTTITIS?
** UNKNOWN
48) Is Pt321's clinical history consistent with OTITIS-MEDIA?
** UNKNOWN
49) Is Pt321 a burn patient?
** UNKNOWN

50) Does Pt321 have focal neurological signs?
** UNKNOWN
 [Determining which drugs are desirable for use against the
       Hemophilus-influenzae...]
51) Does Pt321 have a clinically significant allergic reaction to
     any antimicrobial agent?
** NO

INFECTION-1 is MENINGITIS

   + <ITEM-1>  HEMOPHILUS-INFLUENZAE [ORGANISM-1]


[Considering AMPICILLIN-AND-CHLORAMPHENICOL for use against
INFECTION-1...]
   52) Do you have reason to suspect that Pt321 may have impaired
        renal function?
   ** NO

   53) Pt321's weight in kilograms (or <number> POUNDS):
   ** 20

[REC-1] My preferred therapy recommendation is as follows:
        Give the following in combination:
        1) AMPICILLIN
        Dose: 1.0g (8.0 ml) q4h IV [calculated on basis of 50 mg/kg]
        [The dose should be modified in SEVERE renal failure.  I can
               adjust the dose only if a creatinine clearance or a
               serum creatinine is obtained.]

        2) CHLORAMPHENICOL
        Dose: 500 mg (5.0 ml) q6h IV [calculated on basis of 25
              mg/kg]
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