$1.50

Research Series No. 9

ON THE CONCEPTUALIZATION OF CLINICAL PROBLEM SOLVING

Christian C. Wagner
and John F. Vinsonhaler

Published By

The Institute for Research on Teaching
252 Erickson Hall
Michigan State University
East Lansing, Michigan 48824

Printed and Distributed
by the
College of Education
Michigan State University

May 1978
Second Printing, January 1979

The work reported herein is sponsored by the Institute for Research on Teaching, College of Education, Michigan State University. The Institute for Research on Teaching is funded primarily by the Teaching Division of the National Institute of Education, United States Department of Health, Education, and Welfare. The opinions expressed in this publication do not necessarily reflect the position, policy, or endorsement of the National Institute of Education. (Contract No. 400-76-0073)

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The IRT publishes research reports, occasional papers, conference proceedings, a newsletter for practitioners, and lists and catalogs of IRT publications. For more information, to receive a list or catalog, and/or to be placed on the IRT mailing list to receive the newsletter, please write to the IRT Editor, Institute for Research on Teaching, 252 Erickson Hall, Michigan State University, East Lansing, Michigan 48824-1034.

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Abstract

The Inquiry Theory is described from three perspectives: (1) as a set of statements about clinical problem solving, (2) as a set of computer programs that can simulate and predict the important aspects of the clinical encounter and preceptor instruction, and (3) as a set of behaviors exhibited by the computer system as it simulates particular environments. Examples of how the computer simulates a case, clinician, and preceptor are provided, and the nature of Inquiry Theory predictions is discussed.

Contents

On the Conceptualization of Clinical Problem Solving[1]

Christian C. Wagner and John F. Vinsonhaler[2]

Introduction

This is the first computer science-oriented report on a theory of clinical problem solving developed over the past decade at Michigan State University. The Inquiry Theory of Clinical Problem Solving, as it is known, attempts to clarify and quantify the nature of clinical decision making independent of content, whether in medicine, reading, instructional design, or learning disabilities.

The fundamental concepts of the theory center about the clinical encounter and the clinical preceptor. In all of these fields a "clinical encounter" occurs, during which a clinician attempts to solve a case problem. More specifically, the clinician tries to make two basic decisions. The first is the diagnosis: What is the current state of the case and how does this compare to the case's "best" potential state? The second is the remediation: What actions can be taken to move the case from its current state toward a more desirable state? Once a remedy is chosen, the clinician may then be responsible for carrying out the treatment plan or following the case to make sure the remedy is effective.

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[1]The theoretical work reported herein represents the joint research efforts of Lee Shulman, Arthur Elstein, and the authors.

[2]Christian C. Wagner is a senior researcher with the Institute for Research on Teaching. John F. Vinsonhaler is coordinator of IRT's Clinical Studies research program and a professor of educational psychology.

Another common setting in the fields of medicine, reading, instructional design, and learning disabilities is "preceptor instruction." During preceptor instruction, a student clinician interacts with a case while a senior clinician observes the interaction and provides feedback to the student on his/her performance. The Inquiry Theory deals with the clinical decision-making processes and the quantitative prediction of the significant aspects of the interactions involved in both the preceptor instruction and the clinical encounter.

In developing this theory, our research has focused on the following: clinical encounter, preceptor instruction, the clinician, the case, and the preceptor. Our work began in the field of medicine with the nature of the clinical encounter described by the Inquiry Project (Elstein, Shulman, & Sprafka, Note 1). Since then, we have expanded our interests to defining and simulating cases, clinicians, and preceptors. The medical field has contributed to all of these areas; Harless, Drennon, Marxer, Root, Wilson, and Miller (1973 a, b), Friedman (1973), deDombal and Horrocks (1974), and others have defined such important design specifications in case simulation as: (1) minimizing required student input, (2) maximizing the ease of case preparation by graduate students under clinician direction, and (3) not requiring complete simulation of the natural language interaction for teaching the significant aspects of clinical problem solving.

In the simulation of clinicians, we have been guided by principles of clinical reasoning such as problem spaces (Newell & Simon, 1972) and the hypothetico - deductive model (Elstein et al., Note 1), by all empirical studies of how clinicians perform (Neufeld, Norman,

Feightner, & Barrows, 1975; Barrows, Feightner, Neufeld, & Norman, Note 2), and by research on the importance of empirical data (Leaper, Horrocks, Staniland, & deDombal, 1972). In designing our computerized clinical preceptor, we were influenced by descriptions of the improvement of clinical performance through the use of computer and non-computer aids (deDombal, 1973; deDombal & Horrocks, 1974; Barness, Tunnesse, Worley, Simmons, & Ringe, 1974; Essex, 1975). Clarification of the research paradigms of judgment, decision making, and problem solving was provided by Bordage, Elstein, Vinsonhaler, and Wagner (1977). The medical field continues to contribute to our understanding of clinical problem solving.

Our move from this base in medicine to the field of reading coincided with the formation of the Institute for Research on Teaching at Michigan State University (MSU). Transferring concepts from medicine to reading has clarified the nature and methods of clinical problem-solving research in this area. We have drawn from reading clinicians at MSU, and on the work of Ekwall (1976) and others to delineate current theories of reading acquisition, the reading process, and reading diagnosis. Our major research effort will remain in the reading content area for the present; descriptions of this work are included in Vinsonhaler, Wagner, and Elstein (Note 3) and Vinsonhaler, Wagner, and Elstein (Note 4). We hope to continue, however, with our research on the clinical encounter in learning disabilities, instructional design, and computer repair.

Several research methods have been employed in this investigation of clinical encounter and preceptor instruction. The first is observation. We are carefully observing and analyzing controlled

clinical interactions to gain a knowledge of what actually happens.

The second method is simulation. Given a conception of the processes involved, we create a simulation to mirror our understanding. Through the simulation we can discover the implications of our thought and theory. The simulations most often used are computer simulations that can effectively replicate the intellectual aspects of a clinician, a case, or a preceptor.

A third method of study employed involves comparison across different content fields. With four different fields of study, cross-field comparisons of the similarities and differences in clinical encounters and preceptor instruction often illuminate our problems. Frequently, significant behavior differences can be traced directly to the differences in technology across the fields. This helps us further in defining the important parameters of clinical decision making.

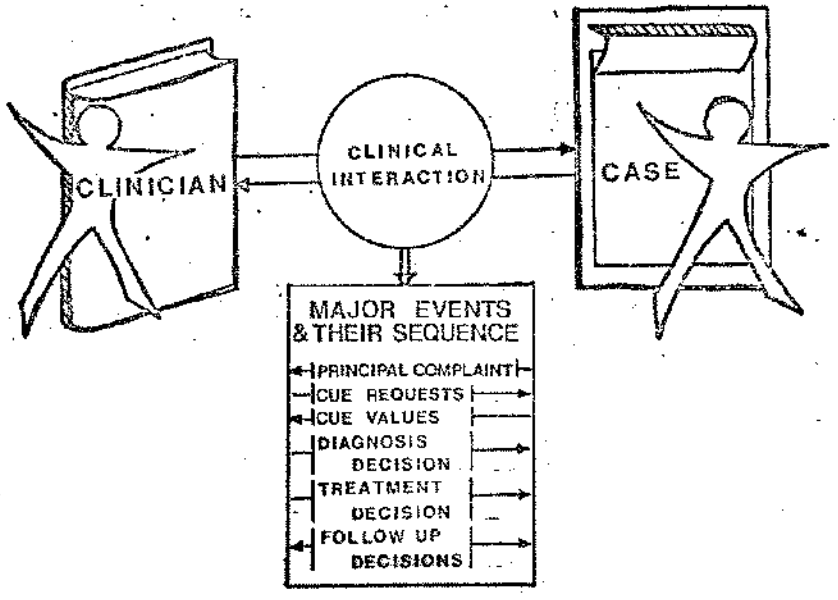
The concepts developed by using these research methods have been formally labeled the Inquiry Theory of Clinical Problem Solving. (We derived the name from the Inquiry Project, Elstein et al., Note 1, upon which much of our work is based.) This theory is embodied in the Basic Management Information System (BMIS), a set of computer programs at Wayne State University. In this paper, we will briefly explain the Inquiry Theory and show the relationship between the theory as stated and the theory as implemented in BMIS. (Further information about our clinical problem-solving research and application work can be found in Vinsonhaler, Wagner, & Elstein, Note 3).

The Inquiry Theory of Clinical Problem Solving

The Clinical Encounter Concept

The central concern of the clinical decision maker is the clinical encounter--the set of events that occur when a clinician interacts with a case in an attempt to reach diagnostic and therapeutic decisions. The clinical encounter is summarized in Figure 1; key behaviors are given with the direction of the interactions indicated by arrows. The Inquiry Theory attempts to unify, clarify, and quantify recurrent aspects of this clinical interaction.

Figure 1. The Clinical Encounter



The case concept. In examining the clinical encounter, we will first consider the case. The Inquiry Theory assumes that the intellectual or cognitive aspects of a case can be effectively simulated by providing the information requested by the clinician. Thus, for

the purposes of our theory, a case is defined by this information; that is, a collection of cue names and cue values forming the data base from which diagnostic, therapeutic, and follow-up decisions are made. Included in this collection are the changes that would occur in response to passage of time and the application of different remediation plans. Any problems present in the case are represented by the difference between a set of cue values in the case and the "normal" cue values.

The clinician concept. The second component of the clinical encounter is the clinician. The Inquiry Theory postulates that the clinician's memory and strategy define his/her clinical decision-making characteristics. His/her clinical memory contains representations for problems, cues, remediation plans, and relationships among them. The clinical strategy consists of a general sequence of information-processing tasks that operate on the clinical memory to produce the diagnostic, therapeutic, and follow-up decisions. Among these information processing tasks are cue acquisition, hypothesis generation, hypothesis evaluation, diagnostic judgment, treatment generation, and treatment evaluation.

The performance and instructional corollaries. There are two corollaries to the clinical memory and strategy concepts, one dealing with the performance evaluation of clinicians and the other with the instruction of clinicians. The Performance Corollary states that, assuming there is a reliable, valid evaluation procedure for the significant aspects of a clinician's clinical performance, the value of that performance will be probabilistically determined by

the case and the clinician's memory and strategy. The Instructional Corollary states that because the performance value is determined in part by the clinician's memory and strategy, changes in the clinician's memory and strategy will result in changes in performance values for a given encounter. Theoretically, valid, reliable evaluations of clinical memory and strategy can be developed that directly relate the quality of memory and strategy to the performance value in diagnostic and remedial problem solving. With these corollaries in mind, we will turn to application and the preceptor mode of instruction.

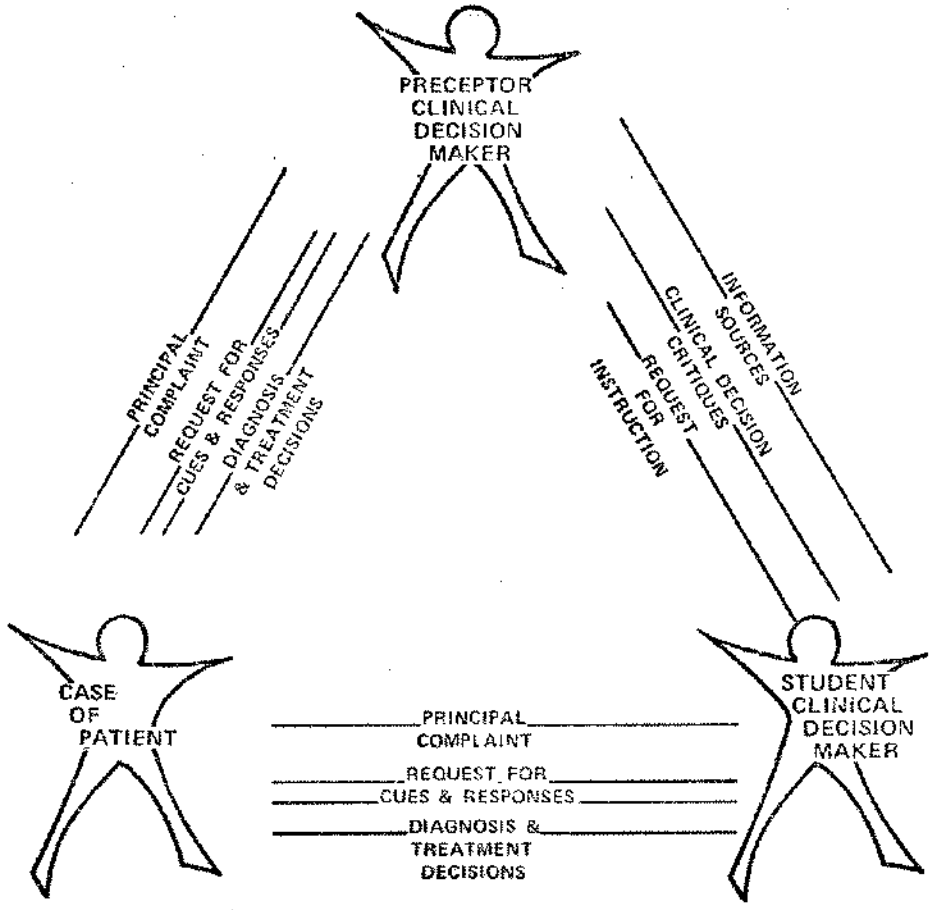
The Preceptor Mode of Instruction

The preceptor mode is an effective method for improving performance through apprentice-type instruction, described in Figure 2; it has been used for centuries in healing and other arts. The preceptor can also serve as a knowledge bank for all aspects of clinical decision-making instruction, because the preceptor is a clinician and an instructor.

The preceptor concept. The first component of this interaction --the case--is conceived of in the same manner as in the clinical encounter; likewise, the student-clinician in conceptual terms, is the same as the clinician. As noted earlier, the preceptor is a clinician, with a clinical memory of problems, cues, treatments, etc. It is an instructor, as well, with an instructional memory of different training methods and an instructional strategy that determines which methods are used and when.

With this brief overview of the clinical Inquiry Theory, we will

Figure 2. The Preceptor Mode of Instruction



now consider the most complete statement of our theoretic model: the computer program.

The Basic Management Information System (BMIS)

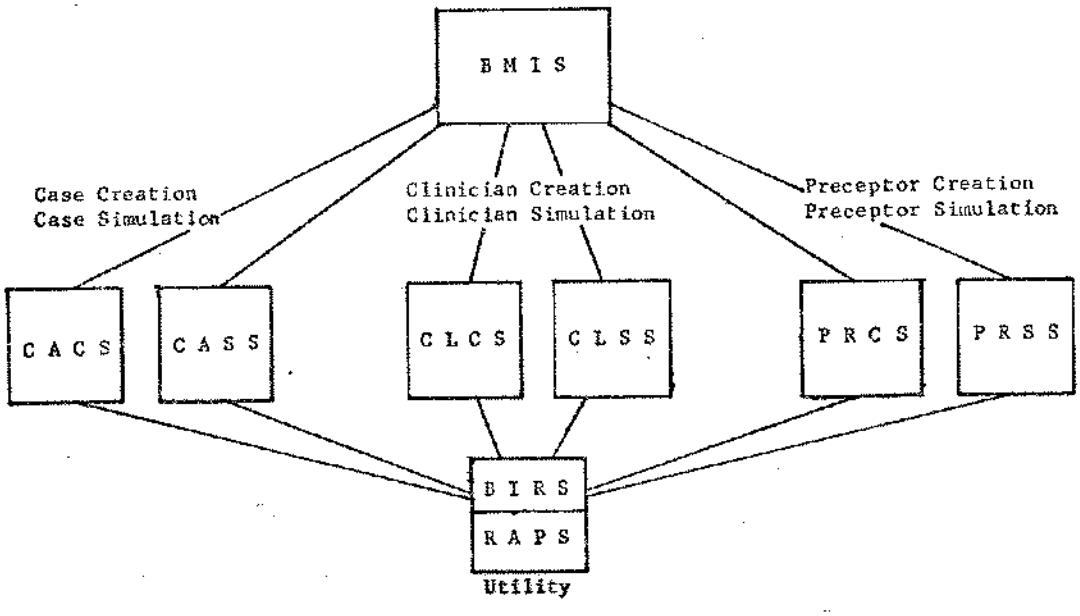
The BMIS system is a more complete, "programmed" version of the Inquiry Theory. One of our goals is to be able to make quantitative predictions about the major events of a clinical encounter and preceptor instruction. For example, we hope to be able to predict the performance of an individual clinician on a specific case. Clearly, such a prediction is not possible with only the stated version of the Inquiry Theory as presented in the first part of this paper. Yet,

predictions of this nature are possible and have often been accomplished with the BMIS system and its simulation capabilities. To the extent that the system operates as we intend, the computer system is the best representation of our theory. Its predictions of human clinical decision-making performance may or may not be correct, but they are quantitative and result directly from a "programmed" theory. Deviations between the prediction and the reality indicate inadequacies in our programmed theory--in BMIS.

The system currently resides on Wayne State University's Amdahl 460/V6 and is available through the MERIT network of Michigan through Telenet. BMIS consists of eight subsystems (illustrated in Figure 3). There are two subsystems for the simulation of each of our three Inquiry Theory concepts (clinician, case, preceptor) and two general utility subsystems. The two utility subsystems are the Basic Information Retrieval System (BIRS), which is the information management subsystem, and the Report Analysis Programming System (RAPS), a gen-

Figure 3.

The Basic Management Information System

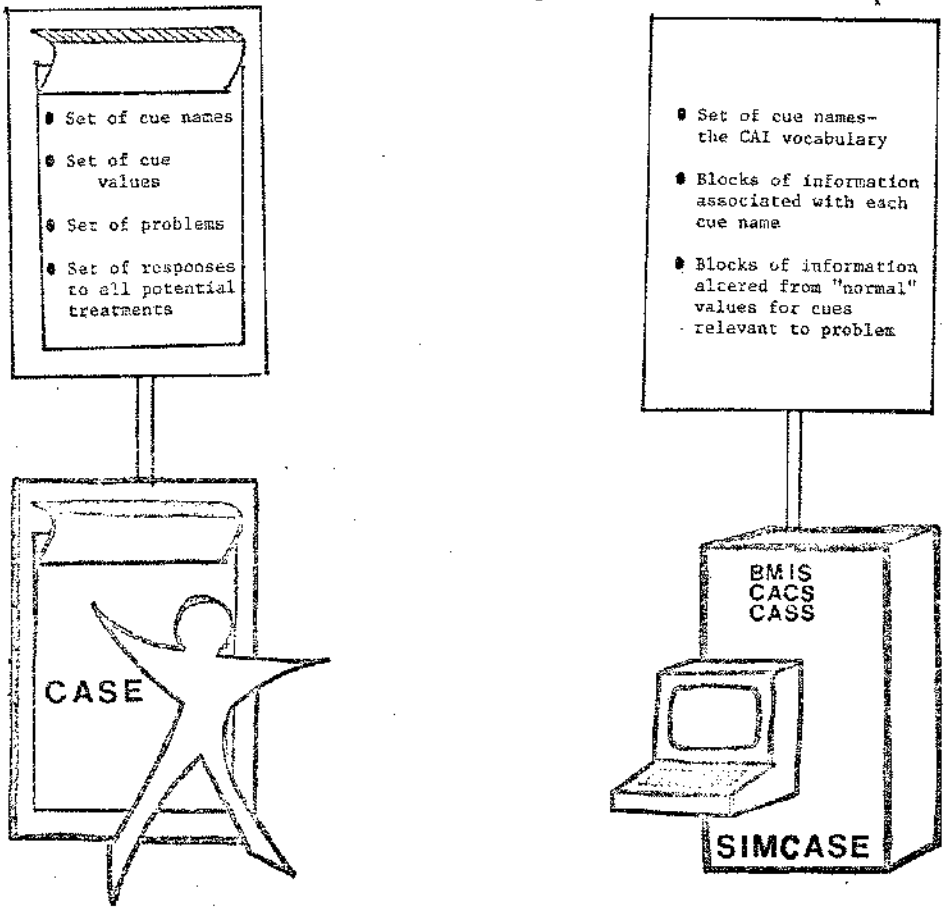


eral report generation subsystem.

The Case Simulation Capabilities

The Inquiry Theory conception of a case is embodied in the Case Creation Subsystem (CACS) and the Case Simulation Subsystem (CASS). The CACS provides the data processing support needed to create and maintain the data files used in case simulation; the CASS simulates a case by providing information to the user in response to requests for information. These requests are made in a vocabulary completely defined by the user; there is no standard terminology. Changes in the case with respect to time or application of treatment require appropriate vocabulary additions. The relationship between the case concept and the CASS is presented in Figure 4.

Figure 4. The Case Concept - CASS Relationship



The following is an example of the CASS simulating a reading case.

```
#$RUN WBSW:BMIS 1=WBSX:STEPHENIFT 2=WBSX:STEPHENDFT
#EXECUTION BEGINS

          THE BASIC MANAGEMENT INFORMATION SYSTEM VERSION 1.2
                THE INSTITUTE FOR RESEARCH ON TEACHING
                    MICHIGAN STATE UNIVERSITY
                            1977

 ?*$cass

 ENTERING THE CASE SIMULATION SUBSYSTEM

?*$case
?*$name stephen
?*$go
 BEGINNING CASE SIMULATION
 THE ENCOUNTER WITH THE CASE BEGINS:
OBSERVATIONS/COMMENTS:
ACCORDING TO THE TEACHER, STEPHEN IS HAVING DIFFICULTIES WITH
READING.  PROGRESS IN ALL OTHER AREAS APPEARS SATISFACTORY EXCEPT
THOSE REQUIRING READING.  STEPHEN'S TEACHER AND HIS PARENTS ARE
CONCERNED AND HAVE REQUESTED A READING CONSULTATION.
TEST DATA:
GENERALLY, SCHOOL TEST RESULTS INDICATE HE IS NOT PERFORMING AT
HIS PROJECTED LEVEL IN MOST READING RELATED ACTIVITIES.
BEFORE YOU CONTINUE ON LOOK AT STEPHEN'S PICTURE IN THE STUDY GUIDE
AND LISTEN TO INITIAL CONTACT TAPE.
ENTER KEYWORD
?bkg2
DATA:       NAME - STEPHEN
            AGE - 8 YEARS 6 MONTHS
            ADDRESS - BURCHAM DR.
                      E. LANSING, MICH.
            SCHOOL - MARBLE
            DISTRICT - EAST LANSING
            GRADE - 3RD
```

```
ENTER KEYWORD
?bkg20
DATA: CLASSROOM BEHAVIOR: TEACHER REPORTS THAT HE ATTRACTS ATTENTION
                          TO SELF INAPPROPRIATELY BUT DOES NOT RESIST
                          CONTROL STATEMENTS.
                          GENERALLY COOPERATIVE IN NON-READING
                          RELATED SUBJECTS, E.G., MATHEMATICS.
                          DISPLAYS IMPATIENCE WITH READING RELATED
                          TASKS.
      PEER RELATIONSHIPS: TEACHER REPORTS THAT SUBJECT TENDS TO BE
                          AGGRESSIVE VERBALLY AND SOMETIMES PHYSI-
                          CALLY.  HOWEVER THE SUBJECT IS NOT ISOLATED
                          BY HIS PEERS.
      ATTENDANCE PATTERNS - NORMAL.
      ATTENDING BEHAVIOR - GOOD.
ENTER KEYWORD
?dur4
SEE:   STEPHEN SIMCASE STUDY GUIDE
       DURRELL ORAL READING AUDIO RECORDING
       (CASSETTE DUR4)
ENTER KEYWORD
?wisc2
EXAMINER'S COMMENTS:  (THIS TEST WAS ADMINISTERED BY THE SCHOOL
                      PSYCHOLOGIST APPROXIMATELY 9 MONTHS AGO.  HIS
                      COMMENTS AND CONCLUSIONS FOLLOW.)
                      - ABOVE AVERAGE INTELLIGENCE WITH EXTREMELY
                        GOOD PRACTICAL KNOWLEDGE AND SOCIAL
                        JUDGMENT.
                      - REFLECTS STRENGTH IN MAKING USE OF
                        INFORMATION IN HIS ENVIRONMENT.
ENTER KEYWORD
?dol3
SEE:   STEPHEN SIMCASE STUDY GUIDE
       DOLCH WORD LIST ANNOTATED TEST BOOKLET
       (ITEM DOL3)
ENTER KEYWORD
?*$diagnose
ENTER YOUR DIAGNOSES (END LIST WITH BLANK LINE)
?sight word problems
?potential adequate
?psychological makeup not problematic
?
 END OF CASE SIMULATION
?*$FINISH
#EXECUTION TERMINATED
```

Clinician Simulation Capabilities

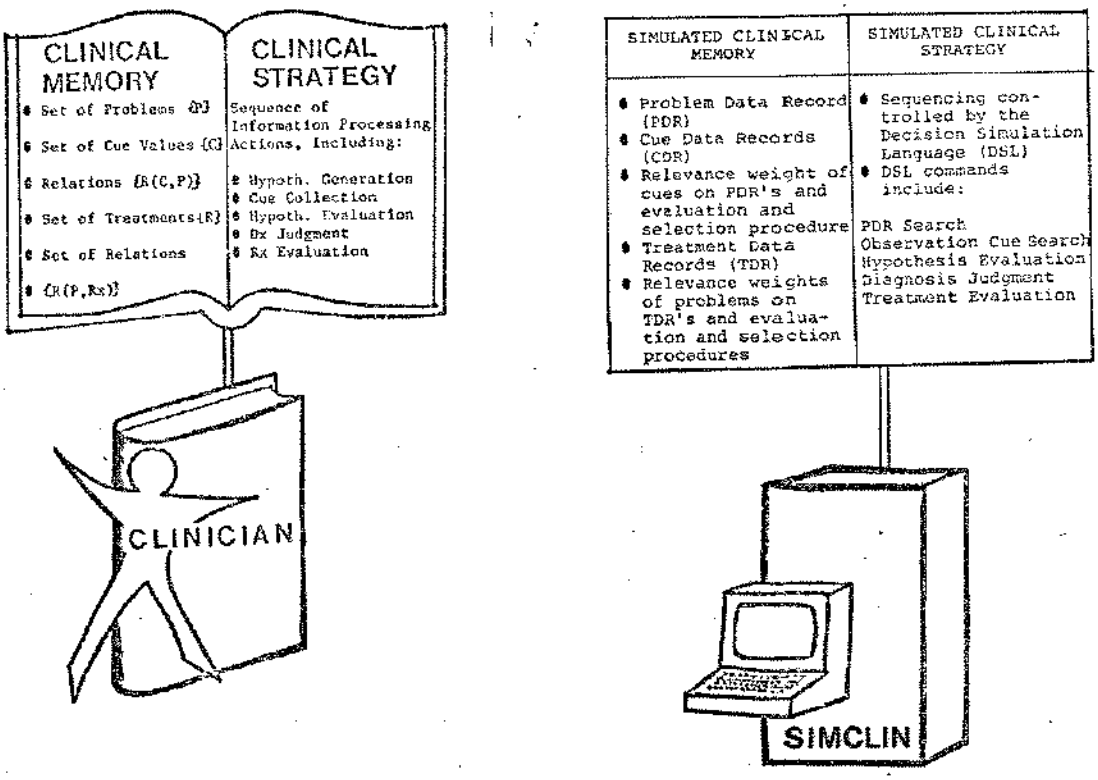
The Inquiry Theory conception of a clinician is supported by the Clinician Creation Subsystem (CLCS) and the Clinician Simulation Subsystem (CLSS). The CLCS manages the data files used in clinician simulation. The CLSS simulates a clinician, including a clinical memory (with representations of problems, cues, treatments, and the relationships among them) and a clinical strategy (composed of a sequence of elementary information-processing tasks that operate on the clinical memory to direct the clinician encounter). Included among the elementary information-processing tasks composing the strategy are initial contact, cue collection, hypothesis generation, hypothesis evaluation, diagnosis judgment, treatment selection, and others.

The CLSS also contains history, observation, and laboratory cue collection tasks for medicine. Two decisions involved in diagnosis are included: (1) whether any of the current hypotheses under consideration are likely enough to be part of the diagnosis, and (2) whether the diagnosis is complete enough to terminate the diagnostic process. Parameters define the maximum size of short- and long-term memory, the maximum number of cues that can be collected in the encounter, how cues are gradually forgotten or reformulated to stay within the confines of memory, the hypothesis evaluation method (possibly Bayesian or discriminant analysis or algebraic weightings), and other features.

In the earlier statement of the clinician concept, many of these decisions and parameters are not mentioned. This further demonstrates that the BMIS system is the most complete manifestation of

the Inquiry Theory. The clinician concept as stated covers the most important aspects of the theory, but the BMIS system more fully describes the theory. (Figure 5 describes the clinician concept - CLSS relationship.)

Figure 5. The Clinician Concept - CLSS Relationship



The following is an example of the CLSS simulating a physician:

```
#$RUN WBSW:BMISX 1=WBSW:FMEDIFT 2=WBSW:FMEDOFT
#EXECUTION BEGINS

THE BASIC MANAGEMENT INFORMATION SYSTEM VERSION 1.1
THE INSTITUTE FOR RESEARCH ON TEACHING
MICHIGAN STATE UNIVERSITY
1976
```

```
?*$clss

 ENTERING THE CLINICIAN SIMULATION SUBSYSTEM
?*$strategy
?*$name clinic
?*$memory
?*$name clinic
?*$diagnose
?*$case is online
?*$go

 BEGINNING CLINICAL SIMULATION

 PLEASE INPUT THE SYMPTOMS AND SIGNS FOR THE INITIAL
 CONTACT WITH THIS CASE.  (END LIST WITH A BLANK LINE)
?the patient, an obese caucasion male over the age of 40, complains
?of headaches, fatigue, and weakness.
?
IS THE PATIENT'S DIASTOLIC BP HIGH?
?yes
HAS THE PATIENT HAD ABDOMINAL PAIN?
?yes
HAS THE PATIENT HAD EXCESSIVE ALCOHOL INTAKE?
?no
HAS THE PATIENT HAD JAUNDICE?
?yes
IS THERE A FAMILY HISTORY OF LIVER DISEASE?
?yes
DOES THE PATIENT HAVE AN ENLARGED LIVER?
?yes
IS THE PATIENT'S LIVER FIRM?
?yes
DOES THE PATIENT HAVE AN ENLARGED SPLEEN?
?yes
IS THERE A FAMILY HISTORY OF HYPERTENSION?
?no
IS THE PATIENT'S DIASTOLIC BP REPEATEDLY HIGH?
?yes
DOES THE PATIENT HAVE HYPERTENSIVE RETINOPATHY?
?yes
**************************************************************************
THE SIGNS AND SYMPTOMS SEEM TO INDICATE THAT THE CLIENT'S PROBLEM(S) INCLUDE:
HYPERTENSION

HAS THE PATIENT LOST HIS APPETITE?
```

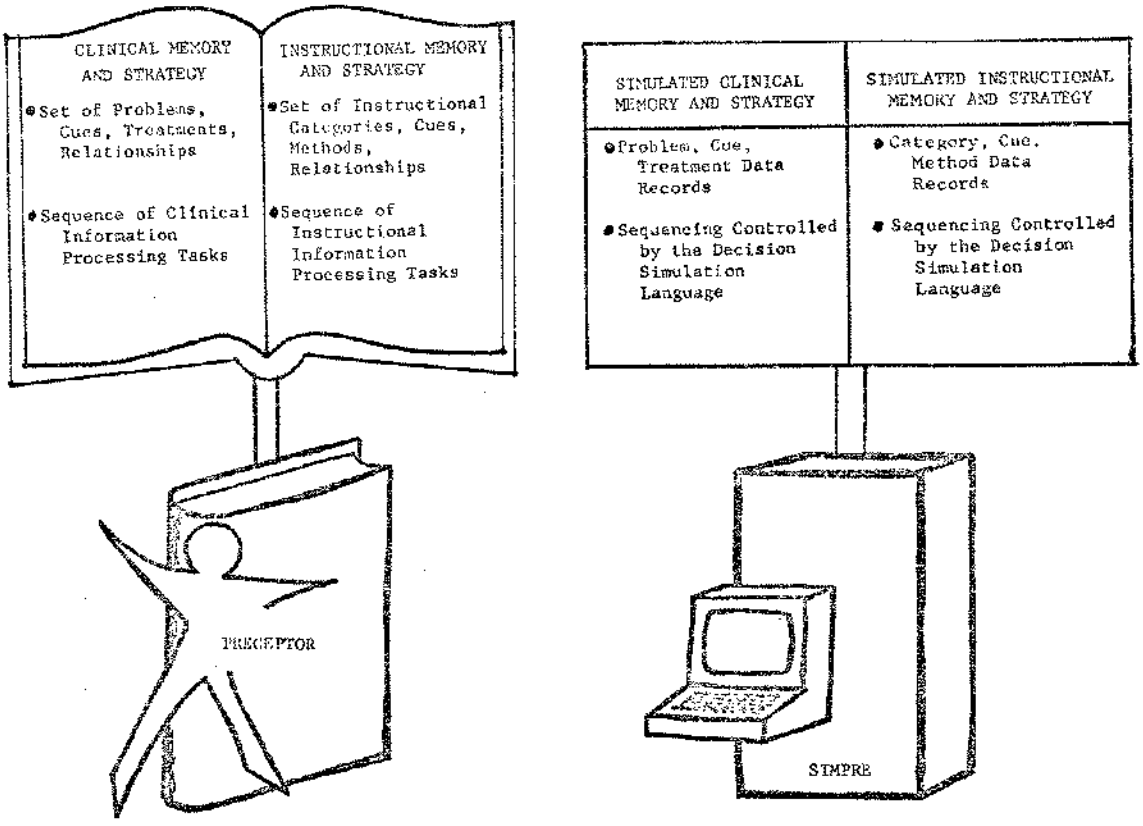
```
?no
HAS THE PATIENT'S TEMPERATURE BEEN HIGH?
?no
DOES THE PATIENT'S LIVER BIOPSY SHOW FIBROSIS?
?yes
DOES THE PATIENT'S LIVER BIOPSY SHOW FATTY CHANGE?
?yes
DOES THE PATIENT'S LIVER BIOPSY SHOW ADVANCED CIRRHOSIS?
?yes
DOES THE PATIENT'S LIVER BIOPSY SHOW BRIDGING?
?yes
DOES THE PATIENT'S LIVER BIOPSY SHOW LIMITING PLATE DISRUPTION?
?yes
**********************************************************************
THE SIGNS AND SYMPTOMS SEEM TO INDICATE THAT THE CLIENT'S PROBLEM(S) ARE:
PRIMARY HYPERTENSION
PORTAL CIRRHOSIS OF THE LIVER

 END OF CLINICAL SIMULATION
?*$finish
#EXECUTION TERMINATED
```

The Preceptor Simulation Capabilities

The Inquiry Theory conceptualization of a preceptor is primitive, as are the Preceptor Creation Subsystem (PRCS) and the Preceptor Simulation Subsystem (PRSS). The PRCS does, however, provide all the data-processing support presently needed by the simulation subsystem. The PRSS simulates the preceptor mode of instruction by presenting a case to a student clinician, observing the case-student clinician interaction, and providing helpful feedback during and after the encounter. In addition, it provides indexed information such as problem-cue associations, problem-treatment associations, cue collection procedures, etc. A preceptor, however, can offer many

more forms of instructional assistance than are currently available in our theory or our system. (The relationship between the Inquiry conceptualization of a preceptor and the PRSS is described in Figure 6.)

Figure 6. The Preceptor Concept - PRSS Relationship



The preceptor mode of instruction is illustrated in the PRSS example as follows:

```
#$RUN WBSW:BMISX 1=FMEDIFT 2=FMEDDFT
#EXECUTION BEGINS
```

THE BASIC MANAGEMENT INFORMATION SYSTEM VERSION 1.1
THE INSTITUTE FOR RESEARCH ON TEACHING
MICHIGAN STATE UNIVERSITY
1976

?*$prss

ENTERING THE PRECEPTOR SIMULATION SUBSYSTEM
?*$simcase
?*$name james walker
?*$preceptor
?*$name clinic
?*$go

BEGINNING PRECEPTOR SIMULATION

THE ENCOUNTER WITH THE CASE BEGINS:
A 47 YEAR OLD WHITE MALE ELECTRICIAN WAS BROUGHT TO THE HOSPITAL IN A STATE OF ACUTE WITHDRAWAL. THE HISTORY AS FOLLOWS WAS OBTAINED FROM RELIABLE FAMILY MEMBERS:
THE PATIENT HAD BEEN DRINKING APPROXIMATELY ONE QUART OF 86 PROOF BOURBON EVERY DAY FOR 35 DAYS BEFORE HIS ADMISSION. DURING THIS TIME, HIS FOOD INTAKE HAD CONSISTED OF SUBSTANTIAL DAILY AMOUNTS OF EGGS, MILK, BREAD AND POTATOES. HE HAD TAKEN TWO OR THREE MULTIVITAMIN CAPSULES DAILY. HE HAD HAD NO VOMITING OR DIARRHEA.

ENTER KEYWORD
?past medical history
SALIENT FEATURES OF THE PAST HISTORY INCLUDE TWENTY YEARS OF ALCOHOLISM WITH FREQUENT HOSPITALIZATION FOR ACUTE INTOXICATION AND WITHDRAWAL WITHOUT OVERT MALNUTRITION.

ENTER KEYWORD
?*$preceptor hypotheses with 2 cues

ENTER YOUR HYPOTHESES (END LIST WITH BLANK LINE)
?none
?
BASED ON ALL CUES WHICH SHOULD BE COLLECTED FOR EACH HYPOTHESES, THE LIKELIHOODS OF THE HYPOTHESES UNDER CONSIDERATION ARE:

RELEVANCE	POSSIBLE DIAGNOSIS
0.0392	CHRONIC HEPATITIS
0.1860	PORTAL CIRRHOSIS OF THE LIVER
0.2647	ACUTE ALCOHOLISM

```
 THE NEXT MOST IMPORTANT CUES TO COLLECT ARE:
     ENLARGED LIVER
     LIVER BIOPSY

ENTER KEYWORD
?liver biopsy
     LIVER BIOPSY SHOWS FATTY CHANGE, ADVANCED CIRRHOSIS,
BRIDGING, LIMITING PLATE DISRUPTION, FIBROSIS, AND
FOCAL NECROSIS.

ENTER KEYWORD
?*$diagnose

ENTER YOUR DIAGNOSES (END LIST WITH BLANK LINE)
?acute alcoholism
?cirrhosis of the liver
?
THE PRECEPTOR DIAGNOSIS IS:
 ACUTE ALCOHOLISM, CIRRHOSIS OF THE LIVER, ANEMIA

 YOUR PERCENT AGREEMENT IS 66%

  THE DIAGNOSIS YOU FAILED TO AGREE  WITH THE PRECEPTOR ON WAS ANEMIA.

 END OF PRECEPTOR SIMULATION
?*$finish
 #EXECUTION TERMINATED
```

Results

The BMIS system enables us to make quantitative predictions about an individual clinician interacting with an individual case and/or preceptor. Discrepancies between those predictions and reality signal flaws in the theory and simulation.

To date, a number of interesting predictions have come out of BMIS. One involved an error study in medicine. A set of cases with known medical diagnoses was created. From each of these cases, three more cases were developed by randomly introducing error into the

cases--errors similar to those that might occur due to incorrect recall of history cues, improperly administered or analyzed lab tests, or physician fatigue or distraction. The cases were diagnosed by a wide variety of simulated clinicians. Results indicated that as error increased, the effectiveness of diagnosis changed little, but the efficiency (i.e., length of time required for diagnosis and the number of cues collected) was drastically reduced. It was further discovered that if the error introduced was in data relevant to the correct diagnosis, the decrease in efficiency was less than if error was introduced in irrelevant data. Close analysis revealed that this was true because the irrelevant data caused the generation of a number of hypotheses not normally considered. Checking out these additional hypotheses took more time, thus decreasing efficiency.

Based on the results of the error study, the Inquiry Theory predicted that the same behavior would be observed in real clinicians. One problem with the simulation study was the small clinical memory used, which might not have been representative of the larger memories of human clinicians.

Another example, which we have not yet been able to reproduce, deals with the size of working memory. Using the full computer memory, we ran a simulated clinician with a case; it considered a large number of hypotheses simultaneously. We then decreased the size of memory, with no noticeable change in the behavior of the simulated clinician until the memory was reduced to about 10 cues. At that point, the clinician switched from the original parallel strategy of testing many hypotheses simultaneously to a linear strategy,

testing each hypothesis, one at a time, until all were tested and the correct diagnosis was obtained.

Discussion

A set of computer programs can be viewed as a device that maps an input to an output. The BMIS system maps a clinical memory, clinical strategy, and a case to a set of events called the clinical encounter; or it maps a student clinician, case, and preceptor to a set of events called preceptor instruction. In this mapping, the system makes certain assumptions about the form of clinical memory, strategy, the case, instruction, etc. and about the significant aspects of the clinical encounter and preceptor instruction. As such, we view the system as a "programmed" version of the Inquiry Theory.

For any particular content area in which the clinical encounter and preceptor instruction occur, the characteristics of the area may impose additional restrictions on memory, strategy, and other theoretical concepts, defining a content-specific theory. For example, the mapping of all possible reading memories, strategies, cases,etc. through BMIS can be considered an "information-processing" version of the Inquiry Theory in Reading. Finally, the different concepts explained here in English can be thought of as a "stated" version of the Inquiry Theory.

Although these different versions of our theory make it difficult to determine the exact definition of the Inquiry Theory, all are used to clarify our thinking on the nature of clinical decision making. We are currently planning to redesign the system and theory,

possibly generalizing the concepts of diagnosis, remediation, and follow-up into successive categorizations and actions based on those categorizations. It is our hope that through continued use of observation, simulation, and comparisons across content areas, and by close examination of the literature, we will be able to clarify these concepts and make more accurate quantitative predictions of clinical problem-solving behavior.

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