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THE SOCRATIC SYSTEM: A COMPUTER SYSTEM FOR AUTOMATED INSTRUCTION

Contract No. AF33(657)-9126

Wallace Feurzeig
Judith R. Harris
John A. Swets

October 1963

Submitted to:

Behaviorial Sciences Laboratory
6570th Aerospace Medical Research Laboratories
Wright-Patterson Air Force Base
Dayton, Ohio

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I. PREFACE

This is the final technical report of a project supported by the Wright Air Development Division of the U.S. Air Force. The aim of the project was to develop a computer system that will serve as a teaching aid in the formation of complex concepts.

The system that was devised, called the "Socratic System," is described in Sections II and IV. Applications of the system are described in Section III and illustrated in Appendices A, B, and C. Associated studies are discussed in Appendices D, E, and F. Our conclusions are stated in Section V.

The authors acknowledge the considerable technical support received from several fellow staff members at Bolt Beranek and Newman Inc., in particular: Myra Breen, who accomplished some much-needed utility programming for the system and ably assisted in preparing the electronic trouble-shooting and medical applications; Dr. Preston Munter of the Harvard University Health Center, a consultant to the project, who designed the medical case problem; Dr. Alfred Kristofferson, who designed the electronic trouble-shooting problems; and Dr. Thomas Marill, who designed an alternative version of the system and consulted during the early period of the research.

II. GENERAL DESCRIPTION OF THE SOCRATIC SYSTEM

The major objective of the initial work was to show that highly complex subject matters could be effectively treated through automated instruction by properly exploiting the logical power of a computer.

The resulting computer program, the Socratic System (Swets, Feurzeig, Harris, and Marill, 1963; Feurzeig, 1963), states a problem to a student and engages him in significant "conversation" while he attempts to solve the problem. The instruction at the computer console begins as the computer types out the statement of the problem. The student is allowed considerable freedom in his approach to solving the problem--he can specify the information he wants when he wants it and he can make assertions as to the solution whenever he wishes. He asks questions and makes declarations via the same console typewriter that the computer system uses for the communications that it initiates. The vocabulary of possible questions and declarations relating to the problem can be of considerable size.

The system keeps a record of the student's questions and declarations, and of all the information the student has been given. The system also has information specifying its own responses, conditionally, as a function of the student's past and current behavior. Each computer response depends not only on what was just said but on everything that went before.

Thus, the system can respond to the student's questions and declarations in the manner of a personal tutor--answering good questions, reproving foolish conclusions, acknowledging perceptive decisions, questioning the grounds of inference, and so on. The pedagogic strategies are open; they are a part of the information specified by the teacher who prepares the problem. In effect, the system carries on a conversation with the student, one in which interesting contingencies may be developed to arbitrary depth. The system's responses are in free, rich English. The problem under study need not be of stationary character; it can embody a situation which changes with time as the interaction develops.

III. APPLICATIONS OF THE SOCRATIC SYSTEM

The system was first applied, primarily to facilitate debugging the program, to a simple letter-guessing game. Exhibits of some plays are reproduced in Appendix A.

It was next applied to a set of problems in electronic trouble-shooting. In this application the object was to simulate a rote learning situation with minimal feedback, i.e., the interest was in drilling toward a fast response rather than in providing insights into the logic of electronic circuit operation. Some of the trouble-shooting runs are shown in Appendix B.

The most recent, and most significant, application of the system was to medical diagnosis. This application illustrates some of the potentialities of the system in a complex setting. It required about 20-30 hours of a doctor and a programmer jointly to set the specifications for the case, including the pedagogic strategies; about 60 hours to compose the English prose with the care that we thought requisite; and about 30 hours of programming time to put in the data which control the interaction. Two runs of the medical case are exhibited in Appendix C.

IV. LOGICAL ORGANIZATION OF THE SOCRATIC SYSTEM

Three types of data must be provided to specify a problem for study using the Socratic System. These are: (1) a vocabulary enumerating the items available to the student for input--the questions that he may ask and the declarations that he may make in the course of his study; (2) the English sentences that constitute the possible responses of the computer; and (3) the "condition-statements" which specify the conditions under which the student's inputs determine the computer's outputs.

Using these data, the computer program operates in the following sequence:

1. It states to the student, via the console typewriter, the problem to be solved.

2. It waits for the student to type in an item from the vocabulary.

3. Upon receipt of information, it evaluates all the condition-statements. This process results in the type-out of one or more English sentences by the computer.

4. It then returns to step 2 of the sequence.

The computer program has to accomplish several "house-keeping" functions, such as: (1) processing the information received from the typewriter, (2) obtaining from memory the English sentence strings needed for output and (3) directing the output of characters to the typewriter.

The computer program also accomplishes a major control function--that of evaluating the condition-statements to generate the responses of the computer. A simple condition-statement, used in the medical application, is stated for illustration:

> Condition-Statement 1: If the student does not know "general appearance" and now asks any question except "general appearance" then output "You should check the patient's general appearance first!"

Some condition-statements are much more complicated.

In general, a condition-statement contains three parts--a set of conditions, a logical operation, and an action. In the simple case, each condition refers to an item in the vocabulary or to the current input of the student. A condition asserts that: (1) a specified question has been answered, or (2) a specified declaration has been made, or (3) the current input of the student is the particular vocabulary item specified, or (4) the current input of the student is a question, or (5) the current input of the student is a declaration. The negations of these five conditions are also allowed.

The specified logical operation (conjunction or disjunction is applied to the set of conditions. If the result is "true," i.e., if the set of conditions is realized, the specified action is effected and the condition-statement is called "valid". If the result is "false," no action is taken. The usual action is the typeout of a specified sentence or set of sentences. Other actions, such as the null action ("do nothing") or the execution of a specified computation, are possible. No action is taken if the condition-statement was already valid.

The condition-statements are not mutually exclusive--more than one may become valid at any time, i.e., as a consequence of a single input from the student. This can result in the generation of several sentences of output at any time.

Condition-statements can be recursive in the sense that they can refer to other condition-statements. This feature is provided by allowing two more conditions, which assert that: (1) a specified condition-statement is valid, or (2) a specified condition-statement is "hot," i.e., has just become valid as a result of the current input of the student. The negations of these two conditions are also allowed.

The use of condition-statements in facilitating a "conversational" exchange over time can now be illustrated:

> Condition-Statement 2: If the student now asserts vocabulary item 1 then output sentence 1.

Condition-Statement 3: If condition-statement 2 is valid, and is not hot, then do nothing.

Condition-Statement 4: If condition-statement 3 is hot, and the student now asserts vocabulary item 2, then output sentence 2.

A particular dialogue that might be driven by these condition-statements is:

Student: "Appendicitis." (vocabulary item 1).

Computer: "Are you absolutely sure?" (sentence 1).

Student: "Yes." (vocabulary item 2).

Computer: "You can't be until you have irrefutable evidence! What evidence would help you nail down this diagnosis?" (sentence 2).

In order to effectively treat non-stationary problems, in which characteristics of the situation being studied may change with time, the system has provision for an internal clock. Thus, one other condition, and one other action, are allowed. The condition asserts that the clock has a specified value. (The negation is allowed also.) The action taken is to increment the clock by one unit. Using these facilities, the system can respond to the same input with different answers, as a function of the (logical) time. Thus, "temperature?" may be answered "98" initially and "103 and rising" later on.

The condition-statement in the general form just described is the key technical contribution to the computer program that approximates our original aim--that of automated instruction through arbitrarily deep interactive exchanges ("conversations") between the student and a subtle "tutor". Other important features of the program, such as the ability to accommodate English sentence strings of arbitrary size, and the ability of the system to accept questions from the student (as well as to direct questions to him), are novel in their application to automated instruction, but are part of the state of the art in other programming applications.

It should be remarked that the system has no semantic content--the meanings of the materials with which it deals are not relevant to its operation. One effect is that the teacher using the system is not bound by any particular, built-in learning doctrines. The computer program merely operates on given strings of symbols in a special way so as to produce other strings of symbols. This special way is called the condition-statement.

V. CONCLUSIONS

We think we have conclusively demonstrated the feasibility of treating complex subject matters by computer-aided teaching. The limits of applicability of the ideas we have developed are not known by us at the present time--we do not have a basis, thus far, for characterizing or classifying either study materials or teaching strategies with respect to their use with the Socratic System. We are convinced, however, that the Socratic System can be fruitfully applied, and that it warrants further exploration and development. We are sure also that there are several interesting applications to substantially different materials than those we have considered thus far.

VI. REFERENCES

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VII. APPENDICES

The three applications of the system are illustrated in Appendices A, B and C. Each includes a single copy of a preamble, defining the problem to be solved, along with two or more photocopies of actual computer runs.

In Appendix A three runs of the alphabet letter guessing game are shown.

In Appendix B, following the electronic trouble shooting preamble, two runs are exhibited. The first one shows a perfect solution to both problems; the second one exhibits somewhat less skilled performance.

Appendix C shows the application to medical diagnosis. The vocabulary of medical terms available to the student is given, followed by the preamble. The first run displays considerable diagnostic guessing and extensive dialogue. The second run represents a more insightful student.

In all the runs the student's queries and declarations are indented and typed in capital letters; this was done so that they might be distinguished, in the photocopy, from the computer's replies. In the original, the student's comments appear in black, and the computer's in red.

In Appendix D some preliminary and related research is summarized.

Appendix E contains a discussion of the considerations involved in a compiler program for The Socratic System.

In Appendix F alternative systems to the present Socratic System are described.

APPENDIX A

Please type your name, the date and a period.

Judy Harris March 19, 1963.

The Alphabet Guessing Game.
I am thinking of a letter of the alphabet -- it could be any letter from A to Z .
You are to try to guess what letter I have in mind.
You can question me about any of seven characteristics of the letter,
and I will answer you truthfully.
The answers to these seven questions differ for each letter of the alphabet --
so if you knew all seven characteristics you should be able to guess the letter correctly.
Some letters are guessable if you know only one or two characteristics.

You are given a drawing of all the letters. This has their graphical "definitions"
and should enable you to infer the answer to any question for any letter.

Whenever you think that only a single letter has the characteristic values given
as the answers to your questions, tell me that letter. I will tell you
whether you're right or not.

The object of the game is to find out the letter with as few questions as possible.

Here are the seven questions you can ask.

1. Enclosures? (How many enclosed spaces does the letter have?)
   (E.g.,O has one, E has none.)
2. Curves? (How many curved lines does it have?)
   (E.g.,I has none, O has one, S has two.)
3. Verticals? (How many straight vertical lines does it have?
   (A has none, I and J have one, U has two.)
4. Horizontals? (How many straight horizontal lines does it have?)
   (P has none, A has one.)
5. Obliques? (How many straight oblique lines does it have?)
   (H has none, X has two, W has four.)
6. Loose ends? (How many loose ends does it have?)
   (A loose end is where a straight or curved line
   comes to an end at a place which is not an intersection.)
   (E.g., O has none, E has three, X has four.)
7. Vowel? (Is it a vowel?)
   (The vowels are A,E,I,O, and U.)

Start when ready.

CURVES?

one.

LOOSE ENDS?

two.

OBLIQUES?

zero.

C.

You don't have enough information yet to get the right answer.
How do you know it isn't J, for example?

HORIZONTALS?

zero.

That was a wasted question. It did not eliminate any possibilities.

VERTICALS?

zero.

Good question.

G.

Wrong. Your guess is inconsistent with the information you've been given.
You must have forgotten that the right letter hasn't any HORIZONTAL LINES.
The letter you guessed can't be right -- it has too many LOOSE ENDS.

C.

Yes, you've done it. Good work.
If you want to play again, start right in.

HORIZONTALS?

zero.

CURVES?

zero.

VERTICALS?

one.

T.

You don't have enough information yet to get the right answer.

You must have forgotten that the right letter hasn't any HORIZONTAL LINES.

How do you know it isn't I, for example?

LOOSEENDS?

two.

Good question.

OBLIQUES?

zero.

You had enough information to get the answer before you asked that question.

I.

Yes, you've done it. Good work.
If you want to play again, start right in.

LOOSE ENDS?

two.

OLBIQUES?
I don't recognize what you just typed-try again.

OBLIQUES?

zero.

VOWEL?

no.

ENCLOSURES?

zero.

That was a wasted question. It did not eliminate any possibilities.

S.

You don't have enough information yet to get the right answer.

How do you know it isn't J, for example?

OBLIQUES?
The answer is still:

zero.

VERTICALS?

one.

L.

You don't have enough information yet to get the right answer.

CURVES?

zero.

X.

Wrong. Your guess is inconsistent with the information you've been given.

I think you only made that guess to see what I would say.

L.

Yes, you've done it. Good work.
If you want to play again, start right in.

APPENDIX B

PREAMBLE FOR ELECTRONIC TROUBLE SHOOTING

You are a technician charged with maintenance of a bomb-nav. system. When the equipment malfunctions, your job is to check it over until you find the cause and can repair it. One item in the equipment is the track button. Normally it is illuminated, but at this critical moment it fails to light. Fix it!- as follows:

When the track button fails to light, there is a routine series of checks which can be made to find the cause. These checks must be performed in a specific order. There are seven checks which can be made. We represent them here by the questions:

1.	bomb button?	(does the bomb button light?)
2.	search button?	(does the search button light?)
3.	track button?	(does the track button light?)
4.	track bulb?	(is the track bulb O.K?)
5.	28 volt pins?	(are the 28 volt pins O.K?)
6.	28 volt breakers?	(are the 28 volt breakers O K?)
7.	circuit breakers?	(are the circuit breakers O.K?)

To find the trouble you must ask at least some and sometimes all of the questions. The number of questions needed and the order in which they must be asked depends on where the trouble is. At any point in time, the question which you should ask depends on the answer which you obtained to your previous question.

There are five possible actions which you may take to attempt to- repair the equipment. These are represented here by the declarations:

1. replace track bulb.
2. replace track and search bulbs.
3. repair wire in box.
4. repair break in cable.
5. repair ground.

When you think you have found the malfunction call for one of these actions and the computer will respond. If the computer executes your repair command and you think the equipment is back in working order ask about the current status of the track button and you will be told if you have solved the problem.

Begin as soon as you are sure you understand these instructions.

SEARCH BUTTON?

The search button does not light up.

BOMB BUTTON?

The bomb button does not light up.

28 VOLT BREAKERS?

The 28 volt breakers are O.K..

28 VOLT PINS?

The 28 volt pins are not O.K..

REPAIR BREAK IN CABLE.

The break in the cable has been fixed.

TRACK BUTTON?

The track button lights up now. Start right in on the next problem.

SEARCH BUTTON?

The search button lights up.

TRACK BULB?

The track bulb is good.

28 VOLT BREAKERS?

The 28 volt breakers are not O.K..

CIRCUIT BREAKERS?

The circuit breakers pop off.

REPAIR GROUND.

The ground has been fixed as you directed.

TRACK BUTTON?

Very good! You've done it again -- the track button is on.

Please type your name, the date and a slash.

JUDY HARRIS JULY 26/

REPLACE TRACK BULB.

The track bulb is perfectly good -- it doesn't need replacement.

TRACK BUTTON?

Your question is out of order. Ask the right one and I'll give you the answer.

CIRCUIT BREAKERS?

You'd better leave the CB's alone! They've got nothing to do with the problem.

SEARCH BUTTON?

The search button does not light up.

REPLACE TRACK AND SEARCH BULBS.

These bulbs are fine -- it would be a waste of time to change them.

28 VOLT PINS?

Your question is out of order. Ask the right one and I'll give you the answer.

BOMB BUTTON?

The bomb button does not light up.

REPAIR BREAK IN CABLE.

What break? The cable looks fine to me.

28 volt PINS?

Your question is out of order. Ask the right one and I'll give you the answer.

TRACK BUTTON?

Wrong question again. Ask another.

28 VOLT BREAKERS?

The 28 volt breakers are O.K..

REPAIR BREAK IN CABLE.

What break? The cable looks fine to me.

REPAIR BR
REPAIR GROUND.

Your analysis is not well grounded -- the circuit is!

28 VOLT PINS?

The 28 volt pins are not O.K..

CIRCUIT BREAKERS?

You'd better leave the CB's alone! They've got nothing to do with the problem.

REPAIR BREAK IN CABLE.

The break in the cable has been fixed.

BOMB BUTTON?

Your question is out of order. Ask the right one and I'll give you the answer.

REPAIR WIRE IN BOX.

You do not have conclusive evidence that the trouble is inside the box.

se
SEARCH BUTTON?

Wrong question again. Ask another.

TRACK BULB?

The status of the track bulb is not relevant at this point.

TRACK BUTTON?

The track button lights up now. Start right in on the next problem.

BOMB BUTTON?

Whether the bomb button lights or not has nothing to do with the case.

SEARCH BUTTON?

The search button lights up.

TRACK BUTTON?

Your question is out of order. Ask the right one and I'll give you the answer.

TRACK BULB?

The track bulb is good.

28 VOLT PINS?

The pins are O.K. but so what? They are not a factor in this trouble shooting situation.

28 VOLT BT
28 VOLT BREAKERS?

The 28 volt breakers are not O.K..

CIRCUIT BREAKERS?

The circuit breakers pop off.

BOMB BUTTON?

Whether the bomb button lights or not has nothing to do with the case.

SEARCH BUTTON?

Your question is out of order. Ask the right one and I'll give you the answer.

TRACK BUTTON?

Wrong question again. Ask another.

TRACK BULB?

This is the third time you've asked a question out of sequence. Take care on your next try.

28 VOLT BREAKERS?

It's not easy to ask more than three questions out of order but you've done it. Try again.

REPLACE TRACK BULB.

The track bulb is perfectly good -- it doesn't need replacement.

REPAIR WIRE IN BOX.

You do not have conclusive evidence that the trouble is inside the box.

REPAIR BREAK IN CABLE.

There's nothing broken in the cable. That was a costly error.

REPAIR GROUND.

The ground has been fixed as you directed.

TRACK BUTTON?

Whew! You managed to get the track button lit but you'd better study some more before you try another problem.

APPENDIX C

VOCABULARY FOR MEDICAL CASE I

QUESTIONS

Physical Exam?

abdominal exam?

chest exam?
- auscultation?
- localized tenderness?
- percussion?
- respiratory excursion?

eent exam?
- distension of neck veins?
- stiff neck?

general appearance?
- backache?
- contact with birds?
- cough?

heart exam?

musculo-skeletal system?
- extremities?

neurological exam?

rectal exam?

vital signs?
- blood pressure?
- pulse?
- respiratory rate?
- temperature?

Laboratory Reports?

differential?

esr?

hemoglobin?

rbc?

wbc?

urine exam?

x-ray?
- evidence of fluid?
- lateral?

blood culture?

nose and throat smear and culture?

sputum culture?

sputum smear?

urine culture?

VOCABULARY FOR MEDICAL CASE I

DECLARATIONS

acute pyelonephritis.

appendicitis.

friedlander pneumonia.

influenza.

mild upper respiratory infection.

pleural effusion.

pneumococcal pneumonia.

primary atypical pneumonia.

psittacossis.

pulmonary infarction.

staph pneumonia.

strep pneumonia.

tb pneumonia.

the grippe.

viral pneumonia.

yes.

no.

proceed.

evidence from blood culture.

evidence from abdominal exam.

evidence from blood test analyses.

evidence from chest exam.

evidence from eent exam.

evidence from heart exam.

evidence from ms system.

evidence from neurological exam.

evidence from nose and throat smear and culture.

evidence from rectal exam.

evidence from sputum smear and culture.

evidence from urine analysis.

evidence from urine culture.

evidence from x-ray findings.

positive evidence of another disease.

possible evidence though inconclusive.

complications.

PREAMBLE FOR MEDICAL CASE 1

Please type your name, the date and a slash.

Myra Breen, August 1963/

It is mid-December. Late this afternoon, a patient was admitted to the hospital. He is a well developed, well nourished, 34-year-old Negro coal miner. He was brought in by his wife who reports that he has had "the grippe" for about four days. During the past 3 days she has given him fluids and aspirin every six hours with no sign of improvement. Today he suddenly became much worse. For the past two days he had complained of feeling very warm and of pain in his belly. This morning he had a severe shaking chill that was so bad his teeth rattled.

You, the admitting physician, are requested to diagnose the case. To obtain the information you need to make this diagnosis, you are required to perform a methodical physical examination of the patient and to order all pertinent lab tests. This is done by typing questions to the computer. The set of questions you may ask is listed in the vocabulary you have been given. The computer will respond to each question with an answer or comment.

When you have finished the examination and lab tests, type: proceed. At this point the day "ends". Before you "go home" you may leave instructions for the night nurse to take a second series of lab tests during the night so the results will be ready for you "tomorrow". It is assumed that the second series consists of just those tests you think necessary.

Tomorrow morning, results of some of the first lab tests will be returned to you; others won't be available until late in the day. On the basis of information you have been able to obtain, you will be asked for the diagnosis. If you feel that no conclusive diagnosis can reasonably be made, you may then perform another full physical exam. Also, reports from the second series of lab tests may be requested.

You may make a diagnosis at any time you choose by typing the name of one of the diseases in the vocabulary. At various times the computer will discuss certain diagnostic possibilities with you. If questions are raised you must answer them by typing a diagnosis or an appropriate declaration from the final section of the vocabulary.

If you make a typing error, press the carriage return key and begin again Please remember that questions must end with a question mark; everything else must end with a period. Begin the physical examination as soon as you are ready.

PHYSICAL EXAM?

Fine. What in particular would you like to know?

CHEST EXAM?

It is common practice in the medical profession to begin an examination by checking the patient's general appearance.

general APPEARANCE?

Acutely prostrated, lying in bed on his right side. Looks acutely ill, sweaty, apprehensive, but alert. Paroxysmal cough, bringing up a little rusty streaked sputum. Breathing with difficulty.

EENT EXAM?

Check all of the vital signs first!

TEMPERATURE?

103.

BLOOD PRESSURE?

150/84.

PULSE?

100 a minute. Occasional extra systole.

RESPIRATORY RATE?

20 a minute and shallow.

ABDOMINAL EXAM?

The EENT exam comes first!

EENT EXAM?

Essentially negative.

CHEST EXAM?

Good. Go right ahead with the chest exam.

PERCUSSION?

Normal.

RESPIRATORY EXCURSION?

Apparently equal. Questionable pain on right side on inspiration.

LOCALIZED TENDERNESS?

Questionable, on right.

AUSCULTATION?

Normal.

COUGH?

Yes, developed yesterday.

BACKACHE?

No.

HEART EXAM?

Not enlarged to percussion but low grade systolic murmur at apex. Otherwise normal.

ABDOMINAL EXAM?

Diffusely tender, some splinting noticed in lower right quadrant and occasionally radiating to right flank area.

THE GRIPPE.

There's insufficient information for any conclusive diagnosis at this time. You're not being careful!

MUSCULO-SKELETAL SYSTEM?

Essentially negative, except for generalized weakness and aching.

EXTREMITIES?

Normal, except nail beds are questionably cyanotic but difficult to determine because of patient's skin color.

PROCEED.

Finished? No, doctor! You're stopping short of a reasonably thorough examination.

RECTAL EXAM?

You're not being careful! The patient is too acutely ill for a rectal examination.

NEUROLOGICAL EXAM?

Negative.

STIFF NECK?

No.

DISTENSION OF NECK VEINS?

No.

LABORATORY REPORTS?

Fine. Which lab tests would you like to have done?

RBC?

A red count will be done.

Results will be sent to you as soon as possible.

WBC?

The WBC will be taken.

HEMOGLOBIN?

Request for hemoglobin noted.

ESR?

The esr will be done for you.

DIFFERENTIAL?

Request noted.

URINE EXAM?

The analysis will be done.

X-RAY?

X-rays will be taken.

LATERAL?

A lateral film will be taken.

NOSE AND THROAT SMEAR AND CULTURE?

They'll be ordered now.

When you've requested all the lab reports you want, let me know that you're ready to proceed.

BLOOD CULTURE?

A blood culture will be done.

SPUTUM SMEAR?

A sputum smear will be done.

URINE CULTURE?

A urine culture will be ordered.

PROCEED.

You may want repeats on some of the lab work.
Would you like to alert the night nurse to set up the lab tests you'll want to see tomorrow?

YES.

Good. That will speed things up.

However, there's nothing further that can be done tonight to help the patient. Let's call it quits for now. Perhaps you'll be in a better position to diagnose the case tomorrow after the first lab reports come in and you have reexamined the patient.

Have a good night's sleep and when you're back on duty tell me to "proceed."

PROCEED.

It's morning and you're making your rounds. You've come to our patient and are given the night nurse's report:
"Temperature remained high but patient spent a reasonably comfortable night. Cough diminished but persists. Occasional traces of blood in sputum. Patient still dyspneic and still has pain in abdomen. The second series of lab tests was initiated."

Some of the first series of lab reports have just come in.
Urine exam: insufficient fluid for analysis.
RBC: 5 million.
WBC: 15500.
Differential: Shift to left.

Hemoglobin: 13.5 grams.

ESR: 11 mm/hr.

When the other reports are in you'll be notified.

Before proceeding with the reexamination it might be instructive to pause and consider the diagnostic implications of the information at hand. Perhaps you think it too early to arrive at any definitive conclusion. On the other hand, you may be prepared to make the diagnosis now. Are you?

NO.

Fine. Nevertheless, we've got a fair amount of information - at least enough to raise some, perhaps several, diagnostic possibilities. Have you any in mind?

YES.

Name one.

PULMONARY INFARCTION.

Fine. Pleural pain, dyspnea, fever and the physical exam signs and symptoms are certainly consistent with pulmonary infarction. Do you think that shaking chills and the presence of rusty sputum further support this diagnosis?

NO.

Right. Though the white count is consistent, isn't it?

NO.

Wrong. The white count is consistent. This should further support your diagnosis.

We've considered one possibility. Do you have another diagnosis in mind?

NO.

In that case I'd like to talk about viral pneumonia. The tachycardia, high WBC, elevated respiratory rate, shaking chills, bloody sputum and severe pleural pain all lend weight to that diagnosis - right?

YES.

You're way off base. There's not an iota of truth to any part of what I just said; in fact, the opposite of what I said is true. You'd better review some elementary medicine, doctor.

Some more of yesterday's lab reports have come in.
Nose and throat smear and culture: no growth after 12 hours.
There was some trouble at the x-ray lab. Please excuse the delay.
The x-rays are normal.

Lateral: no evidence of fluid, no evidence of consolidation.

Now let's see how the patient is today. Begin the physical when you're ready.

PHYSICAL EXAM?

Fine. What would you like to know?

VITAL SIGNS?

Take a look at your patient first.

GENERAL APPEARANCE?

Essentially unchanged since last night.

The last of yesterday's lab reports are in.

Sputum smear: After 12 hours - occasional beta hemolytic strep and staph aureus organisms.

Blood culture: Negative after 12 hours.

Urine culture: negative after 12 hours.

PULMONARY INFARCTION.

Yes, I remember you liked this diagnosis before.

There's no question of the need to account for this possibility. You're thinking - but rule it out, won't you, on the basis of the history of shaking chills, high temperature and somewhat excessive WBC.

TEMPERATURE?

103.

PULSE?

105/minute. Still occasional extra systole.

RESPIRATORY RATE?

24/minute and still shallow.

BLOOD PRESSURE?

130/84.

ACUTE PYELONEPHRITIS.

Very good. You should think of acute pyelonephritis. It's consistent with many of your patient's signs and symptoms - but not all. Wouldn't you want some signs of dysuria to support this diagnosis? And what about the respiratory symptoms in the history and findings? You'd better reevaluate the evidence.

FRIEDLANDER PNEUMONIA.

A wise thought - but off the mark. You don't have the usual Friedlander pneumonia gelatinous type sputum nor the klebsiella organism - do you? Hold off on this diagnosis for a while.

EENT EXAM?

Unchanged, except for mildy injected pharynx.

CHEST EXAM?

Fine. What do you want to know?

RESPIRATORY EXCURSION?

Change in respiratory excursion. Left greater than right. Questionable pain on right on inspiration.

PERCUSSION?

Posteriorly - normal on left, some dullness right base.
Anteriorly - normal. Some tenderness to percussion over right base.

AUSCULTATION?

Normal breath sounds on left, anteriorly and posteriorly.
Right:-posteriorly, normal upper 2/3 of chest, base diminished breath sounds; anteriorly, upper 2/3 normal breath sounds, base slightly diminished.

LOCALIZED TENDERNESS?

Questionable on right.

THE GRIPPE.

"La Grippe?" Nonsense!

INFLUENZA.

Come, come. You know that in influenza there is an absence of almost all positive physical signs, don't you? Review the evidence carefully, doctor.

APPENDICITIS.

Sounds good! But what about the history of cough and the chest signs? What evidence would help you establish this diagnosis?

EVIDENCE FROM ABDOMINAL EXAM.

Right! Go to it.

ABDOMINAL EXAM?

The heart exam should be done before this.

HEART EXAM?

Unchanged, except systolic murmur more prominent.

ABDOMINAL EXAM?

Pain localizing in lower right quadrant with continuing diffuse abdominal tenderness.

APPENDICITIS.

Appendicitis? Nonsense. By this time you should have your attention focussed on a different part of the patient's anatomy.

MUSCULO-SKELETAL SYSTEM?

Unchanged.

PLEURAL EFFUSION.

A good contender, but let's be careful. What evidence would rule it in or out?

POSITIVE EVIDENCE OF ANOTHER DISEASE.

Is there such evidence?

POSSIBLE EVIDENCE THOUGH INCONCLUSIVE.

Since you aren't sure, continue the examination until you have conclusive evidence one way or the other.

URINE EXAM?

The urine analysis will be ready shortly; ask for it a little later. The blood reports are probably ready now.

RBC?

An RBC is not indicated at this time. It's an unnecessary expense for a poor patient.

WBC?

22500.

STAPH PNEUMONIA.

Fair enough. But where is the guilty organism? - When you have isolated staphylococcus aureus in significant numbers in your samples of this patient's fluids or excretions, let me know.

PNEUMOCOCCAL PNEUMONIA.

Are you absolutely sure?

YES.

You can't be until you have irrefutable evidence.

What would help you nail down the diagnosis?

EVIDENCE FROM SPUTUM SMEAR AND CULTURE.

Good. Anything else?

NO.

I think you might also want evidence from x-ray findings. Go ahead and we'll see what happens.

X-RAY?

Not ready yet. Try the blood lab.

DIFFERENTIAL?

Marked shift to left.

Even though all the lab reports aren't in, you have enough information to make a presumptive diagnosis. If you care to make one go right ahead.

ACUTE PYELONEPHRITIS.

It's getting hard to hold onto this diagnosis with neither history nor signs of dysuria. Moreover, the pain is getting away from the flank region into the lower belly. Still thinking of a renal problem? Reconsider.

TB PNEUMONIA.

Any other thoughts as to diagnosis? The sudden high rise in WBC and differential is against it and you don't have tubercle bacilli in the sputum.

URINE EXAM?

The urine test shows presence of albumen, few hyaline casts, few WBC, occasional RBC.

X-RAY?

The x-ray shows: area of consolidation, right lower lobe, consistent with pneumonic process. This is a good time to review the total findings and make another tentative diagnosis - if you like.

EVIDENCE OF FLUID?

No evidence of fluid.

SPUTUM SMEAR?

Gram positive rods.

STREP PNEUMONIA.

Fine, but how can you distinguish this from any other bacterial pneumonia? Wait until you have an irrefutable case.

VIRAL PNEUMONIA.

But what about shaking chills, rusty sputum, elevated WBC, etc. - all the evidence of an acute febrile bacterial process? You are in error, doctor.

SPUTUM CULTURE.

I don't recognize what you just typed - try again.

SPUTUM CULTURE?

Presence of pneumococci.

STREP PNEUMONIA.

Incredible! You have disregarded the positive findings that should clearly have established the correct diagnosis.

PNEUMOCOCCAL PNEUMONIA.

Very good. It's obvious now, though there were some confusing signs and symptoms in the picture. You've seen your way through to the correct diagnosis.

Please type your name, the date and a slash.

DR. SOCRATES 1963 /

GENERAL APPEARANCE?

Acutely prostrated, lying in bed on his right side. Looks acutely ill, sweaty, apprehensive, but alert. Paroxysmal cough, bringing up a little rusty streaked sputum. Breathing with difficulty.

PULSE?

100 a minute. Occasional extra systole.

TEMPERATURE?

103.

bLOOD PRESSURE?

150/84.

RESPIRATORY RATE?

20 a minute and shallow.

EENT EXAM?

Essentially negative.

CONTACT WITH BIRDS?

None, except patient has pet canary.

RESPIRATORY EXCURSION?

Apparently equal. Questionable pain on right side on inspiration.

PERCUSSION?

Normal.

AUSCULTATION?

Normal.

LOCALIZED TENDERNESS?

Questionable, on right.

HEART EXAM?

Not enlarged to percussion but low grade systolic murmur at apex. Otherwise normal.

ABDOMINAL EXAM?

Diffusely tender, some splinting noticed in lower right quadrant and occasionally radiating to right flank area.

MUSCULO-SKELETAL SYSTEM?

Essentially negative, except for generalized weakness and aching.

RBC?

A red count will be done.

Results will be sent to you as soon as possible.

DIFFERENTIAL?

Request noted.

WBC?

The WBC will be taken.

URINE EXAM?

The analysis will be done.

X-RAY?

X-rays will be taken.

NOSE AND THROAT SMEAR AND CULTURE?

They'll be ordered now.

When you've requested all the lab reports you want, let me know that you're ready to proceed.

PROCEED.

You may want repeats on some of the lab work.
Would you like to alert the night nurse to set up the lab tests you'll want to see tomorrow?

YES.

Good. That will speed things up.

However, there's nothing further that can be done tonight to help the patient. Let's call it quits for now. Perhaps you'll be in a better position to diagnose the case tomorrow after the first lab reports come in and you have reexamined the patient.

Have a good night's sleep and when you're back on duty tell me to "proceed."

PROCEED.

It's morning and you're making your rounds. You've come to our patient and are given the night nurse's report:
"Temperature remained high but patient spent a reasonably comfortable night. Cough diminished but persists. Occasional traces of blood in sputum. Patient still dyspneic and still has pain in abdomen. The second series of lab tests was initiated."

Some of the first series of lab reports have just come in.

Urine exam: insufficient fluid for analysis.
RBC: 5 million.
WBC: 15500.

Differential: Shift to left.
When the other reports are in you'll be notified.

Before proceeding with the reexamination it might be instructive to pause and consider the diagnostic implications of the information at hand. Perhaps you think it too early to arrive at any definitive conclusion. On the other hand, you may be prepared to make the diagnosis now. Are you?

NO.

Fine. Nevertheless, we've got a fair amount of information - at least enough to raise some, perhaps several, diagnostic possibilities. Have you any in mind?

YES.

Name one.

PNEUMOCOCCAL PNEUMONIA.

Good. The general signs of a pneumonic process are present. Of course, you haven't isolated the bug. Do you think the belly pain and flank pain reinforce the case for pneumococcal pneumonia?

NO.

Right. Though the white count is consistent, isn't it?

YES.

I think so too, but a later reading is indicated to confirm this finding.

We've considered one possibility. Do you have another diagnosis in mind?

NO.

In that case I'd like to talk about pulmonary infarction. What I like about that diagnosis is the presence of high fever, rusty sputum and shaking chills; I don't like the dyspnea, pleural pain and signs of consolidation - do you agree?

NO.

You're quite correct. I was just trying to see whether or not you were alert - and you were.

Some more of yesterday's lab reports have come in. Nose and throat smear and culture: no growth after 12 hours.

There was some trouble at the x-ray lab. Please excuse the delay. The x-rays are normal.

Now let's see how the patient is today. Begin the physical when you're ready.

GENERAL APPEARANCE?

Essentially unchanged since last night.

TEMPERATURE?

103.

PULSE?

105/minute. Still occasional extra systole.

RESPIRATORY RATE?

24/minute and still shallow.

BLOOD PRESSURE?

130/84.

PNEUMOCOCCAL PNEUMONIA.

Yes, I remember you liked this diagnosis before.

Are you absolutely sure?

NO.

What would help you nail down the diagnosis?

EVIDENCE FROM SPUTUM SMEAR AND CULTURE.

Good. Anything else?

EVIDENCE FROM X-RAY FINDINGS.

Good. X-ray shows area of consolidation at right lower lobe, consistent with a pneumonic process. Lab reports gram positive organisms in the sputum smear and the presence of pneumococci in the culture.

Had you thought to rule out things like appendicitis and acute pyelonephritis? Apparently you weren't thrown off by the referred abdominal pain. In any case you've made the correct diagnosis.

Appendix D. Preliminary Research

Earlier work under the project was devoted to the automation of teaching materials in paired-associate form. While this work has led to several interesting conclusions (Licklider, 1962), other results have made it appear that a more detailed, parametric examination of automated procedures for paired-associate materials is not advisable. The learning of such materials appears to be relatively insensitive to procedural manipulations. In fact, extensive experimental studies of learning to identify nonverbal sounds (Swets, Millman, Fletcher, and Green, 1962; Swets, Harris, Sprague, and Rudloe, in preparation), together with parallel studies of the learning of verbal associations (e.g., Sidowski, Kopstein, and Shillestad, 1961; Cook, 1963) suggest that the procedures of automated instruction do not facilitate, and may even be detrimental to, the learning of materials in paired-associate form. In both of the cases mentioned, the usual automated procedures were found to be less effective than a procedure in which the pairs of elements to be associated are simply observed, without continual interrogation of the student, overt response, or knowledge of results.

Specifically, Swets, et al. (1962), in two separate experiments, found simple presentation with no overt response to be more effective than interrogation plus overt response plus feedback. A particularly ineffective variant of the latter procedure is one in which the stimulus element

corresponding to an incorrect response is presented along with a re-presentation of the stimulus element, before a second try is made. These investigators also found a small-step, logically-ordered, "part" procedure to be less effective than a "whole" procedure in which the entire set of pairs to be learned was presented in a random order, again in two different experiments. An attempt to enhance the ability to identify sounds by a variegated procedure--which employed different aspects of automated instruction at different stages of practice in a presumed developmental order--was also disappointing; this procedure, too, was no more effective than procedures that were standard before the advent of automated instruction.

Being reluctant to accept these results at face value without additional replications, Swets, et al. (in preparation) conducted an experiment in which the subject had moment-to-moment control over his mode of training. He could simply expose himself to the sound-label pairs; he could hear the sound and test his ability to construct the correct label; or he could compose a given label and produce the associated sound. In all cases he could restrict the set of sounds under consideration to any given subset of the total set to be learned. The results provide detailed support of the earlier conclusions: success was negatively correlated with the proportion of time spent in active responding, receiving feedback, and making second tries.

The results in this perceptual-learning task are in exceptionally close agreement with results obtained by Sidowski, et al. (1961) in a verbal task utilizing English-Russian

vocabulary equivalents. In the latter case, a procedure which simply presented the stimulus-response pair was as effective as two procedures which presented the pair and required copying of the response, and these three procedures were superior to three procedures involving anticipation and confirmation (interrogation, response, and feedback). This result was obtained despite the fact that waste motion was introduced into the simple observation procedure in order to equate trial time, thus reducing the additional effectiveness of the simple procedure that is naturally gained by presenting more trials in a given practice period.

It is probably too soon to conclude with any conviction that all materials in a paired-associate form suffer from the usual techniques of automated instruction, but we have regarded the evidence as a strong push to redirect our own efforts in the field of programmed learning. However, that may be, it should be clear that we were also positively inclined to examine the learning of complex concepts; we believed that a computer could be programmed to be of substantial value in aiding the learning of subject matter not easily reduced to pairs of elements.

Appendix E. Compiler Design Considerations

There was not sufficient time under the project for writing a compiler program to facilitate input of problem data. However, preliminary design considerations have been worked out and are summarized now.

The compiler would be composed of three routines: for input of the vocabulary, of the possible computer output sentences, and of the condition-statements. The first two routines exist in part. A preliminary version of the first routine has been written and was used, in the medical application, to input the vocabulary of terms for the case under study.

The second routine would accept English sentence inputs, including some with short reference names (labels), provide names for internal reference for use by the third routine, and store the sentences for retrieval at run time. Substantial parts of the programming for this routine exist already.

The third routine would translate condition-statements, stated in conveniently abbreviated English, into the octal codes required for the internal operation of the program.

We would also like to develop an on-line compiler program. This program would be made cognizant, as it operates, of relationships among the data it is receiving.

Our objective is to enable the system, during the input process, to communicate information back to the teacher as he is inserting condition-statements. The system might be able to aid the teacher considerably by commenting on the completeness and consistency of the problem data.

Appendix F. Studies of Alternative Systems

Our goal was to facilitate computer-aided teaching with very complex problem materials. To accomplish this we instrumented a system that can accept very complex directions about the conditions which determine the response of the computer to the input from the student. The resulting system is very general in that any contingency, defined by the student's total or partial behavior in the course of his actions, can be recognized and utilized to effect a response. The cost of this generality is the specificity required for explicating all the contingencies of interest.

There are two ways to reduce this cost--by the use of compiling programs that can accept and expand significantly smaller numbers of directions than required presently, or by devising systems that have explicitly incorporated into them conditions for recognizing particular contingencies of interest. Compilers have been considered in Appendix E. We now review the status of the work on a system alternative to the one we implemented.

The alternative system we have considered (really several variations of a single scheme) is designed to explicitly incorporate a set of logical condition recognizers. It is aimed at treating problems for which the solution strategies are adequately described by the standard categories of deductive inference--redundancy, necessity, sufficiency, consistency, and the like. Thus, it is less general than the system we have implemented. The interest in it lies in the savings that may be achieved in the time to prepare a problem, for those problems to which it is applicable.

The basic assumption underlying the alternative version is that a problem may be completely characterized by a matrix of characteristics (represented by questions) versus possible solutions (represented by declarations). Its operation is based on the observation that every time a question is answered the number of solutions still possible is reduced (though perhaps by zero). The idea is to incorporate programs that are executed, following each input of the student, to determine for any question whether it is logically redundant, for any declaration whether is it logically consistent with known information, and so on. The system, knowing the set of possible solutions at any point, can answer guesses by suggesting alternative possibilities consistent with known information. Knowing which question is optimal, in that it minimizes the number of solutions remaining at that point, the system may comment on the "goodness" of questions. Other similar logical contingencies can be included.

Using this version, the input information for a problem is the matrix of characteristics of possible solutions. In the more general version, the major input is the set of condition-statements. For those problems that can be treated with both versions, the question of ease of input is primarily determined by comparing the size of the matrix with the number of condition-statements.

This determination has not as yet been made for particular problems. It should be noted that the conclusion will not obviously favor the matrix--there may be problems for which the total set of characteristics for the false solutions need not be explicated as input to the more general version, whereas the matrix must always be completed, and it may be quite large.

Thus far our expectation is that there are problems for which the alternative version is nicely suited, there are problems for which the general version is preferable, and still others where the general version is required (such as the application to medical diagnosis illustrated in Appendix C).

This question may be of much less interest in the future when the general version is supplemented by a suitable compiler. The relevant comparison for the matrix, then, will be with the statements of a problem-description language that is more natural and powerful than the current condition-statement language.