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ABSTRACT

A major problem in teaching symbolic logic is that of providing individualized and early feedback to students who are learning to do proofs. To overcome this difficulty, a computer program was developed which functions as a line-by-line proof checker in Sentential Calculus. The program, DEMON, first evaluates any statement supplied by the student to see whether it is well-formed; second, it checks each line of the student's proof to determine whether it is a legitimate inference from the premises and earlier lines of the proof. This program, combined with a second which offers drill and feedback on translating English to and from logical symbols, is the key part of an integrated computer assisted curriculum in informal and formal logic. It is argued that these "simulations" of logical processes, in conjunction with the CAI approach, enable college students to acquire an understanding of symbolic logic more quickly and at a higher level than courses using more conventional methods. (Author/BM)

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LOGIC AND SIMULATION

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LOGIC AND SIMULATION

Abstract

A major problem in teaching symbolic logic is that of providing individualized and early feedback to students who are learning to do proofs. Ordinarily, the teacher first sees samples of such proofs only after notational and procedural errors are already ingrained, and must be unlearned. And some students have so much difficulty in getting started that they cannot produce completed proofs at all, and have nothing to submit for correction. In large classes the instructor is unable to offer the kind of concentrated and individualized help that may be needed.

To overcome this difficulty a computer program was developed which functions as a line-by-line proof checker in Sentential Calculus. The program, DEMON, first evaluates any statement supplied by the student to see whether it is well-formed; second, it checks each line of the student's proof to determine whether it is a legitimate inference from the premises and earlier lines of the proof. This program, combined with a second which offers drill and feedback on translating English to and from logical symbols, is the key part of an integrated computer assisted curriculum in informal and formal logic.

It is argued that these "simulations" of logical processes, together with the CAI approach in which they are embedded, produce a teaching system wherein college students acquire an understanding of symbolic logic more quickly and at a higher level than they do in courses using more conventional methods.

Further, it will be argued that programs such as DEMON and BERTIE (a proof checker developed at Dartmouth College), which evaluate statements and arguments presented by students instead of being limited to a particular repertoire, are theoretically distinct from conventional models of computer assisted instruction and constitute instances of "artificial intelligence."

Simulation of Cognitive Processes

In one sense "simulation" in logic is a misnomer. Logic, like mathematics, traditionally includes the construction and study of representations and models of its own structures within the discipline itself. So to the extent that a simulation of something must be a copy or imitation and not the thing itself, logic cannot be simulated; a model of logic *is* logic. But in a different sense, logic itself is a simulation of something else--it is a model so old we tend to forget that it is a representation at all. Of course, what logic simulates is the structure of thought itself; it is a model of cognitive processing.

In general, two different kinds of goals might be pursued by a simulator of a cognitive process such as logical inference (deduction). A psychophysiologist, for example, might want to model the way in which the process proceeds in a human subject. The details of such a model might be suggested by experimental findings regarding the actual steps and stages a human being goes through in performing an inference task, or, the model might be strictly a heuristic device, a representation of an unconfirmed theory about what such a process might be like. The model might be based upon physiological events only, or else upon introspective reports--so called "protocols" of thought (detailed answers to the question "What steps did you go through to get that answer?"), or both. But all of these, which I call "process" simulations, are essentially similar in that what is being simulated is the way in which the outcome is thought to be produced in the system being modeled. The criterion for classifying a model as a process simulation is not correctness of the model, but intent to model a process.

Logic is not a process simulation. Although Aristotle called his three axioms of logic "Laws of Thought," few psychologists or logicians have held that untaught reason goes through the very steps of a logical proof in making an "intuitive" inference. Instead, what logic does is provide a reliable route from "here" to "there": Building on the immediate plausibility of some inferences ("Rules of Inference"), longer and more complex problems can be solved than could be tackled by the unaided intuition alone. But even were we to assume that those same rules of inference are "wired" into the nervous system, there would be no reason to believe that complex human inferences proceed in the manner of a formal proof. And of course, formal logic doesn't show why the rules or axioms appear plausible to humans--it depends upon that plausibility. Therefore, logic no more simulates immediate inference than a telescope simulates sight. Both extend human capabilities. It may be fair to push the analogy a bit further and say that what both logic and the telescope "simulate" is a kind of superhuman capacity to reason or see, over and above the ordinary or lazy way of doing these things. We might say that telescopes (and eyeglasses) simulate "having better eyes" if the result of using these devices is like actually having better eyes, whether or not the optical system of the artificial device in any way models or resembles that of a pair of better eyes. For this reason, I call the telescope an example of an "input-output" simulation.

In an input-output simulation, "raw materials" similar to those processed by the system being modeled are transformed into a "finished product" resembling the output of the original system. But the mechanism by which the transformation takes place in such a dynamic simulation is irrelevant: it may be safely represented in the flow chart of the model by a black box. Examples of input-output simulations, in addition to the telescope, are artificial heart and lung machines, pacemakers and other functional but non-biological body parts, the pitching and serving machines used in baseball and tennis, and so on. Such devices as vending machines, which "simulate" salespersons, are so familiar that it is easy to forget that they are indeed simulations.

Of course, calculators and computers are also input-output simulations, and so are logic and mathematics. In fact, the former are input-output simulations of the latter, while the latter are input-output simulations of such cognitive processes as inferring and calculating. Hence a dynamic simulation such as a computer program which "infers" or "calculates" by producing proofs or solving mathematical problems deserves the designation "artificial intelligence." In my view, it is not necessary to have devised a process simulation in order to make such a claim.

Simulating the Teaching of Logic by Computer (CAI)

Two different modes of computer assisted instruction (CAI) are utilized in our comprehensive program for the teaching of symbolic logic. One of them involves conventional CAI techniques, namely the presentation of new material via alternating lessons and feedback exercises. The only sense in which this sort of computer program is a simulation is a trivial one; the computer "simulates" a part of the behavior of a classroom teacher conducting drill and review exercises. However, we also utilize a program which can be said to constitute "artificial intelligence" according to the criteria described in the previous section. This program falls into the broad class of computer-assisted instruction to be sure, but because it independently arrives at logical conclusions through an "inferential" process, it provides feedback of a sort that has been previously available only from a human instructor. Thus, it qualifies as an input-output simulation of cognitive processes. For example, first, our program checks logical sentences (formulas) provided by students to determine whether they are well-formed and internally consistent. Second, it ascertains whether the formulas follow from the premises and/or previous steps of an argument. In this, it is not limited to a stored repertoire of questions and answers as is the case with conventional CAI programs. Any problems furnished by the students (within very liberal limits) is capable of being analyzed by the computer. Third, the program has the capacity to diagnose a wide variety of logical and syntactical errors, and to provide hints and specimen solutions to problems.

Objectives of CAI in Logic

At a large university, the motive for computerizing instructional materials is often primarily economic. CAI appears to be a relatively efficient technique for administering mass education. At a small liberal arts college like Denison, our motives have been quite different. Since we offer only one all-purpose course in logic, the student clientele served by it tends to be heterogeneous, and the students' objectives in taking the course also vary considerably. CAI enables an instructor to individualize both the content of the course and the rate at which material can be presented. Since the students learn certain materials faster and more completely at the computer terminal than from lectures, the savings in class time can be utilized for curriculum expansion and enrichment. It is especially apparent that students can learn more material more quickly when certain kinds of topics such as translation into symbolic language and proof techniques are taught outside of class. This is because the rate of mastery of these topics is particularly a function of student ability. The computer enables practically all students to reach a minimum threshold of understanding, although they may require different amounts of time in which to do it. CAI contributes to a more efficient use of the time of instructors and assistants as well. Formerly, teachers were required to repeat material many times before feeling confident that a majority of class members had reached a satisfactory level of understanding. Now an instructor can concentrate upon the conceptual elements in a course such as Logic, leaving much of the teaching of skills and techniques to the computer. Student morale appears to be enhanced by this combination of teaching methods.

By contrast, the conventional method for teaching students to do proofs involves demonstrating a few specimen proofs in a lecture setting and having students attempt some exercises at home. Under this system, the student receives no feedback until examination time, when errors are likely to be ingrained. Also, by then the evaluation process has begun, creating an environment in which new learning and error correction are eclipsed in importance. Indeed, under the traditional approach, some students never reach the first threshold of competence in doing proofs, and thus receive no helpful feedback at all. In contrast, the computer provides early, instantaneous, and detailed feedback in an environment which is nonjudgmental and maintains the student's privacy. Virtually all students manage to begin to produce proofs in this setting. This dramatic fact alone justifies the use of CAI in the teaching of logic.

The Denison FRAME Programs

The conventional CAI component of our integrated computer package in logic consists of a series of exercises we call FRAME programs. This is because they are keyed to frames of the programmed textbook* we use for the teaching of translation to and from symbolic language. The FRAME programs provide explanations, corrections, additions, extra practice exercises and feedback, each one related to a particular lesson in the textbook. Like other conventional CAI programs, the FRAME programs are limited to the specific repertoire of exercises stored in the computer's memory and offer the student feedback to only those of his or her responses that the designers of the programs were able to anticipate. Experience with these programs will enable us to make them more versatile, but not to overcome this inherent handicap of conventional CAI programs.

Proof-Checking Simulations: DEMON and BERTIE

The most innovative feature of our computer package in logic is, of course, our proof-checking program, which we call DEMON ("Demonstration"). The major credit for the programming of DEMON belongs to Robert Manfredi, a Denison senior Chemistry major who had been a teaching assistant in Logic. When DEMON was designed, we believed that it was the only simulation of its kind, but later we learned of the existence of BERTIE, a computer program with identical objectives which was developed at Dartmouth College by two faculty members,

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*Schagrin, Morton L., The Language of Logic (New York: Random House, 1968).

James Moor and Jack Nelson. BERTIE and DEMON have the following features in common: Both allow the student to choose whether to solve practice problems stored in the computer's memory or to furnish his or her own. The repertoire of problems which the programs can assist students in solving is thus unlimited. Both programs are capable of providing a series of exercises carefully graduated in difficulty and designed to provide practice in the use of all applicable rules of inference. Both check each line of student input for coherence as well as correctness (DEMON specifies which logical or syntactical error is being made), and both have the capability of evaluating the student's claimed justification for each line of the proof. Both are able to evaluate any proferred solution, and to certify any correct proof, no matter how circuitous. BERTIE goes further than DEMON in providing instruction in doing proofs in two different symbolic languages, Sentential (Propositional) Calculus and Predicate Calculus, while DEMON handles only proofs written in the former language.

Evaluation of the Denison CAI Package in Logic

This is the first semester in which the complete Denison CAI package is available for classroom use. Data has been collected establishing norms for student achievement in Logic during previous semesters when conventional teaching methods were employed exclusively. As many factors as possible are being held constant to facilitate the evaluation of the CAI Logic Project. These include syllabus, class size, contact hours, instructor and textbooks used. Student achievement is evaluated by means of objective written tests compiled by the instructor from a pool of problems of similar difficulty. The evaluation process does not utilize the computer in any way; a basic premise of the project has been that the computer serves exclusively as an instructional device. Although variations in the capabilities of the students who elect to study logic could distort our evaluation data, admissions statistics for the period of the study suggest that no such effect is likely.

A report on this comparative evaluation of our project will be available by early Summer 1977. Inquiries about the project are welcome, and we are willing to share our programs with others who are engaged in the teaching of symbolic logic. In the same spirit we would like to acknowledge the generosity of the designers of BERTIE and their distributing agents, CONDUIT of Iowa, who have unhesitatingly shared their work with us.

Technical Information

Language of FRAME and DEMON: Basic Plus, Ver 06A

Language of BERTIE: "Dartmouth" Basic (The distributing agent for BERTIE is CONDUIT, P. O. Box 388, Iowa City, Iowa, 52240.)

Denison Computer: Digital Equipment Corporation, Model PDP 11/45; Operating System RSTS/E. Nine-track magnetic tapes, 800 bpi (8 bit ASCII) and PDP11 type DEC tapes are available at cost for transfer of FRAME and DEMON.