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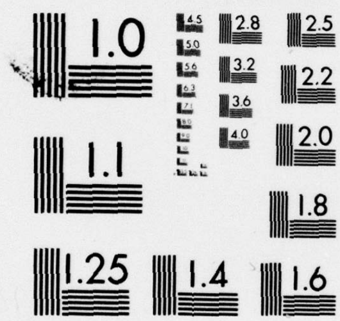

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This project examines the learning of complex topics. The research was aimed at two different aspects of the study of learning and instruction: 1) theoretical understanding of what is going on in the learner's mind; 2) development of intelligent interactive computer-based instructional systems. Two computer-based tutorial systems, Coach and Instruct, were developed. The findings of our research are summarized.

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STUDIES OF LEARNING AND SELF-CONTAINED EDUCATIONAL SYSTEMS, 1976-1979

Introduction

This is the final report for Contract N-00014-76-C-0628, covering the period of 1 February 1976 through 31 January 1979. The goal of the project was to increase knowledge about the psychological mechanisms of learning and of teaching complex materials. One focus of the work was the investigation of fundamental principles of instruction; the other major focus was the development of operational computer-based tutorial systems which could be used as testbeds for the study of these principles, and also as prototypes for potential applications.

Several computer-based tutorial systems were explored. One such system was the FLOW Tutor, a completely automated tutorial system for teaching a basic computer programming language. This system uses an active semantic memory representation of the knowledge about programming, of the manual being read by the student, and of the knowledge that the student has acquired. The system has been implemented on a computer allowing for assessment of its potential capabilities.

A second tutorial system is the "incremental tutor" system. This is a semi-automated facility which uses a state-dependent teaching strategy, allowing for intelligent interaction between the automated parts of the tutor, a human tutor who is called in when necessary, and the student. This system was also implemented on a computer and used to teach students in experiments on different forms of instructional strategies.

These experiments with tutorial systems and with the presentation of materials to students have provided us with means for the assessment of teaching strategies and advanced our theoretical understanding of the process of learning.

Theoretical work concentrated on two aspects of learning: first, that learning is not a homogeneous process, but that several different forms of activity are involved; second, that the role of prior knowledge is critical and students must be presented with appropriate conceptualizations and metaphors for the proper understanding of the new knowledge they are acquiring.

At the conclusion of this contract, two major experimental systems for instruction were implemented on a small laboratory computer, numerous students had been examined going through the learning of several different topic matters, and considerable advance in our theoretical understanding of the nature of instruction had taken place.

Overview

This project examines complex learning. Recent advances in our understanding of the human memory system, especially the way in which information is represented, have led to significant advances in our understanding of memory and, therefore, of learning. Similarly, recent advances in the development of interactive computer systems that couple with a rich knowledge base of information promise significant advances in the ability to devise interactive instructional systems. Learning, however, involves more than the simple placement of new information into a student's memory. Instruction involves more than merely noting student difficulties and presenting appropriate new advice or information.

The studies reported here were directed at two different aspects of the study of learning and instruction: the theoretical understanding of what goes on in the mind of the learner, and the development of intelligent interactive computer systems for instruction. Significant progress has been made in all domains. However, considerable work remains before we will achieve an adequate understanding of the learning process. Similarly, considerable work and development must take place before we come to have sophisticated, intelligent teaching systems.

The results already obtained can have practical applications. We believe we have learned enough about the learning process that advantage can be taken in practical teaching and instructional situations. Small interactive instructional systems can be built for specialized topic domains. Our demonstration project of an interactive tutor shows that it is indeed possible to have intelligent tutoring of a specialized topic. Our work and the work of others has shown that if the topic to be instructed is chosen with care, so that the topic is properly constrained, well understood, and defined with some care, then impressive results can be obtained with interactive computer-based tutorial systems (see Burton & Brown, 1979; Goldstein, 1979).

This report summarizes the accomplishments of this project. The details have been presented in technical reports and publications, as referenced within this document. In addition, a book summarizing the theoretical aspects of this project is in progress (Norman, in progress). A good brief summary of the overall accomplishments was published in the Naval Research Reviews (Norman & Gentner, 1978).

Advances in the Understanding of Instructional Theory

The basic notion underlying the development of instructional systems is simple. Considerable progress has been made in the representation of knowledge of complex topics. These representations take on various forms, but they mostly fall within the generic class of network or schema theories of representation. Basically, one represents the knowledge that is meant to be conveyed to the student by means of a semantic network. A second semantic network is used to provide a model of the student, showing the presence and absence of relevant knowledge structures for the topic to be acquired. Instruction, then, can be thought of as the process of transferring from teacher to student those knowledge structures in the topic matter that are not present in the student. We believe this formulation is a reasonably viable model for some kinds of learning situations. However, it fails for lack of consideration of the activities engaged in by the learner. The learner is not a passive being. A learner selects which aspect of the material to attend to and then reinterprets that material, so that the information the instructors think they are presenting is often quite different from the information the students might perceive the instructors to be presenting.

In our studies of learning, we spent considerable effort examining the growing knowledge structures of the students as they went through various instructional materials. We carefully devised instructional materials of various sorts and on different topics. We presented these to students in controlled circumstances, sometimes one sentence at a time, while we carefully observed the student's performance.

In order to understand even simple material, considerable knowledge is required. The terms and the concepts that must be understood have a surprising richness of structure. In order to understand a computer text editor, one has to understand the purpose of editing, the nature of manuscripts, and the way in which one might wish to alter an existing manuscript. One must also come to understand computers, at least at a level at which the operation of particular programs can be understood. One also has to know something of the file structure for storage, including storage within a particular program, working storages, and the difference between the immediate RAM memory of the machine and the back-up store (disk, tape). Students often have images of computers that include such notions as omnipotence. They have to understand the concept of a text editor as a limited instruction-following system that was designed by someone for a limited purpose. Thus, text editors do not necessarily follow the organization expected by the students, and many of the decisions involved in the design of a text editor are of necessity quite arbitrary.

Our goal is to teach the computer text editor to people who know nothing about computers. Indeed, the designers of these editing systems do not believe it should be necessary to understand computers in order to use the system. We soon discovered that students were devising models of the computer and of the system they were learning. Their models tended to be capricious and misleading. We discovered that during instruction, while students are actively interpreting the material being presented to them, it is essential for the instructor to have control over the students' models. This means that it is the instructor who must present models for students to use. Of course, this poses severe practical difficulties, since in order to present any body of knowledge, one has to present an appropriate conceptual basis. As that basis is itself a topic matter that must be instructed, it too requires some conceptual basis. The recursion suggested by this analysis is obviously unworkable. One effective instructional method is to identify possible prototype systems that students will be able to use as a basis, systems with which the students can be expected to already be familiar. Thus, in teaching about the computer text editor, we began to use the technique known as "teaching by analogy." We selected from the three models of a tape recorder, a human secretary, and a card file to illustrate various components of the operation of the text editor.

Learning by analogy, or learning by using metaphoric analysis of the situation with reference to another previously understood situation promises to be an important area for future directions of this research. Unfortunately, the full appreciation of the nature of the active strategies being employed by the students did not become apparent before the end of this contract period, and so only the briefest excursion into teaching via metaphor was carried out. We recommend further studies along these lines, believing that reasonably large increments in general knowledge of the instructional process can be made by following this approach. The best summaries of this work can be found in Norman (in press) and in Bott (1979).

Studies of Memory

Because memory is a major component of learning, considerable effort was spent on increasing our knowledge of the memory structure. One set of studies expanded our knowledge of the organizational structure of memory -- the notion of schemas. Thus, it is now believed that a considerable amount of information in memory is organized into structured units. Consideration of schemas leads in several directions. One is the understanding of the relationship between the development and completion of schemas and learning. This led us to the realization that learning can take place in at least three different modes: accretion, restructuring, and tuning (Rumelhart & Norman, 1978.) Learning is not a unitary process, and so we should not expect a single explanation to account for the different processes that must go on. Similarly, instruction for the different phases of learning must take on different forms.

A second aspect of memory involves the retrieval of information previously learned. Norman and Bobrow (1979) pushed the study of the retrieval effort, inventing the notion of "description" and its role in the process of retrieval. The use of description emphasizes the way that partial knowledge can lead eventually to appropriate recall in some circumstances, or to inappropriate recall or complete failure in others. In a related study, Williams (1978) studied in detail the processes by which people retrieve memories from the long past. The studies of schemas, descriptions, and retrieval expand our knowledge of the memory system in ways directly relevant to the study of instruction. In another related study, Miyake and Norman (in press) examined how people are able to realize when they lack the appropriate information and how they then formulate questions about that information. This is an issue that gets at the heart of the interactive process between the student and the instructor, and we showed that students ask questions primarily when their lack of knowledge is well-matched to the level of instruction. Students who are exposed to instruction at a level that is either too advanced or too elementary tend not to ask questions.

Computer Based Tutorial Systems

Two major computer-based systems were developed. One, called Coach, was a fully automated tutorial system for instruction in a computer language, based upon a semantic network representation of the topic, of the instruction manual, and of the student's knowledge. The other, called Instruct, was a testbed for instructional research, with a semi-automated tutorial environment, one that allowed for incremental increase in the interaction between the computer system and the student. This system was used to explore the teaching of a variety of topics.

Coach

Coach is a working demonstration system capable of tutorial assistance in the learning of a simple computer programming language. Coach uses a semantic network schema-based knowledge structure of the topics that are being learned, coupled with an analysis of the student's progress through the course material to interpret the student's actions and give relevant coaching advice where required. Coach represents a prototype of a new generation of computer-assisted tutorial methods which teach via a deep understanding of both the topic matter to be covered and the knowledge levels of the students. As might be expected, however, the system requires considerable power and memory capacity. It is not yet feasible to use this system in a real environment with the machines that are realistically available today. But this situation is rapidly changing, and it is likely that sophisticated tutorial systems along the lines of Coach could be implemented on a machine costing in the $10-20,000 range within the next few years, with prices continuing to drop at a rapid rate as the technology required to build machines of the LISP class expands.

Coach has not been used to tutor real students. On the machines currently available to us, we are unable to maintain a system capable of teaching the entire topic matter of the programming language, and even for the small segment of material that is operating, there are often considerable machine delays. Nonetheless, the working version of Coach does represent a working example of a prototype development in a new direction. For a summary of the operation of the Coach system, see Gentner (in press); Gentner & Norman (1977).

Instruct

A second major program was the development of an "incremental tutor," an experimental design for an interactive system which uses the best of both human and automated tutoring. The aim here is to make a system that will supplement the human tutor. This could enable either one human tutor to cover many more students than would normally be possible, or it would allow relatively unskilled tutors to answer questions. The basic premise behind this system is that a complete automated tutorial system for various complex topics is beyond the current state of the art. However, some of the basic principles of tutorial instruction can be implemented, and it is certainly possible to devise intelligent systems that have some understanding of the topic matter that is being presented, that are able to devise a simplified model of the student, and that can handle a limited range of tutorial assistance. Thus, it is possible to devise systems that can give limited tutorial assistance or that can give aid to a human tutor when necessary. That is, when the system cannot fulfill the task itself, it can call in the human tutor, alert the tutor to the problem, and give a tentative diagnosis of what is occurring. It is even possible to give a tentative list of suggested tutorial strategies, letting the human tutor select one of them or any other means to aid the student.

The Instruct system was successful in its use as a test-bed of instructional systems (Norman & Gentner, 1978). Some of the principles resulting from these studies can be applied to instructional systems, and some have played critical roles in the developing theoretical understanding of learning and teaching described in the first section of this report.

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