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ABSTRACT

The goal of the programmatic research program for the Minnesota Adaptive Instructional System (MAIS), an intelligent computer-assisted instruction system, is to empirically investigate generalizable instructional variables and conditions that improve learning through the use of adaptive instructional strategies. Research has been initiated in the integration of individual difference variables within the student model by extending the learner assessment process to include cognitive, affective, and memory models, and instructional variables associated with the learning conditions of verbal information and cognitive strategies have been tested. Two important features of the current version of MAIS are that it distinguishes between individualized instruction and self-instructional teaching, and it employs a cognitive psychology approach to the selection of instructional strategies. Within the macro or curricular level of the MAIS, variables are defined that relate directly to the concepts of memory and cognition, while at the micro or instructional level, variables are defined that relate to the concept of learning. These two levels interact in an iterative fashion such that the initial conditions of instruction established by the expert tutor model in the macro level adapts at the micro level according to learner progress and needs in learning. Descriptions of the nine instructional variables that form the possible meta-instructional strategies and a discussion of continuing research directions conclude this paper. Thirteen references are listed. (MES)

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MAIS: An Empirically-Based Intelligent CBI System

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The past 15 years have seen an increasing growth in the use of computer technology in education and training. However, improvements in learning as a result of using this technology have not yet been realized (Clark, 1985). A major obstacle in the lack of learning improvements is the failure of instructional designers to successfully integrate learning theories with the unique attributes of computer technology (Petkovich & Tennyson, 1984, 1985). Typically, computer-based instructional design strategies have been univariate in applying learning theories; relying mainly on the use of methodologies found in non-technology assisted learning systems instead of fully employing the computer's capabilities. The conventional instructional strategies for computer-assisted instruction (CAI) include drill and practice, tutorials, games and simulations (Allessi & Trollip, 1985). In terms of employing computer capabilities, the use of graphics in games and simulations are well developed but with minimal direct influence in improving learning. However, the capabilities of computer hardware and software design make it possible to develop learning environments that can integrate a range of instructional strategies currently known to improve learning as well as making it possible to add new strategies.

Demonstration programs in education using artificial intelligence/expert systems methods have shown that the computer's more powerful attributes can be applied to instruction (Tennyson & Park, in press). These few prototype ICAI systems, (e.g., SOPHIE, SCHOLAR, WUMPUS, and others), however, continue to limit themselves to the use of one instructional strategy or learning variable within their tutor models. The focus of the developers for the ICAI prototypes has been on how to more fully employ the power of the computer by applying intelligent software programming techniques. However, even with extending the use of such computer attributes, a major ICAI limitation is still the unidimensional approach to learning and, therefore, the use of one instructional strategy regardless of the learning need and individual differences (e.g., the Socratic method used in many ICAI programs). In summary, the educational applications of computers have not in large part been fully realized because of both the apparent narrow use of learning theories and instructional strategies and the failure to fully exploit the power of the computer (see also Seidel, 1978).

My research objective, as focused in my research program for the Minnesota Adaptive Instructional System (i.e., the MAIS), is to empirically investigate generalizable instructional variables

which are clearly defined within an educational psychology perspective. My goal, along with my colleagues, is to significantly contribute to instructional theory and practice such that instructional system developers will have appropriate variables by which to design and implement good instruction.

MAIS Research Program

The goal of our programmatic research program for the MAIS has been to investigate instructional variables and conditions that improve learning through the use of adaptive instructional strategies. To accomplish this research goal, we have extended the research focus of the MAIS in two important ways.

-First, by initiating research in the integration of individual difference variables within the concept of the student model. This was done by extending the learner assessment process to include a cognitive model (e.g., intelligence, aptitude, achievement) and an affective model (e.g., motivation, perseverance, personality) along with a student memory model. The elaborated student model is integrated at the curricular level with the knowledge base to provide the means for iteratively updating the adaptive instructional strategies at the instructional level. An important task in this regard has been the design of an expert tutor model capable of developing for each student different perspectives on the the prescribed instruction.

-Second, by testing instructional variables associated with the learning conditions of verbal information and cognitive strategies (Gagne, 1985). In our early investigations (reviewed in Tennyson, Christensen, & Park, 1984), the MAIS research program tested nine instructional variables directly related to the learning of intellectual skills and conditional information (i.e., concept and rule learning) (see also Tennyson & Christensen, in press). Our more recent work, for example, is looking at the use of adaptive simulation variables to improve both content acquisition as well as development of cognitive strategies (i.e., higher-level thinking skills). Implied in this research effort is the continued development of the MAIS expert tutor model at the instructional level. With the integration of the curricular expert tutor model, we are able to extend the formal heuristic methods of the inference engine of the MAIS to the more advanced methods of inference making offered by informal heuristic methods (Fisher, 1986).

Our current research effort focuses on the study of instructional variables and conditions on a longitudinal basis, so as to further develop the MAIS to include the additional management requirements for the curricular level. Thus, the MAIS

provides us with the opportunity to study the integration of the curricular component with the instructional component. The iterative relationship between the two components provides a means for refining both the curricular as well as the instructional needs per individual student. The basic theoretical model of the expanded MAIS is presented in Tennyson and Park (in press).

MAIS: Adaptive Instruction

Also, we distinguish here between individualized instruction and self-instructional teaching. The former refers to how students are assessed and assigned instruction while the latter is a method of instruction. An integral condition of the research-based intelligent management system of the MAIS is that it adapts to individual learner needs based on assessments occurring externally and internally to the instruction. Typically, assessments are made prior to and/or after the instruction. Our research findings show that student assessment during learning is a powerful method of adapting instruction to the student's moment-to-moment learning needs (Park & Tennyson, 1980). Furthermore, the system employs an iterative method of intelligence such that the management decisions will become increasingly refined the longer the student is in the learning environment. This form of iterative updating of the decision making process is in direct contrast to most current ICAI methods of reactive decision making.

Another important feature of the research-based MAIS, is that it employs a cognitive psychology approach to the selection of instructional strategies (Tennyson & Cocchiarella, 1986). Basically, the MAIS deals with the concepts of learning, memory, and cognition within the framework of the curricular and instructional levels of education and training. That is, the MAIS defines instructional variables and conditions that predictably improve (a) the acquisition of information, (b) the storage and retrieval of knowledge, and (c) the creative and thinking processes. The potential of the computer in terms of its power and speed for variable manipulations and calculations makes it possible to construct an AI instructional system capable of handling the complexity presented by the application of an instructional theory that accounts for learning, memory, and cognition.

Design of the MAIS

The MAIS is designed around the three concepts of learning, memory, and cognition within the conditions of curriculum and instruction. Figure 1 presents a graphic representation of the current version of the MAIS. Within the curricular or macro

level, we define variables that relate directly to the concepts of memory and cognition, while at the instructional or micro level, we define variables that relate to the concept of learning. The variables within the macro component establish the conditions of curriculum while the micro component adapts the instruction to meet moment-to-moment individual student learning needs. Both components interact in an iterative fashion such that the initial conditions of instruction established by the expert tutor model in the macro adapts at the micro level according to learner progress and needs in learning.

Insert Figure 1 about here

The basic research goal the MAIS project has been to approach intelligent management systems from a curricular level instead of the conventional instructional-only level. Typical designs for computer-based management systems have rarely expanded the function of management beyond that of student record keeping and have operated with branching routines composed of finite-sets of possible remediations and options.

A primary purpose of the MAIS research program has been to investigate individual difference variables that would contribute to the initial conditions of instruction within the specifications of a given curriculum. A second purpose has been to investigate variables and conditions by which adaptive instructional systems can iteratively update the conditions of instruction as the individual student progresses through the curriculum. The term "dynamic" is used to describe this relationship between the macro- and micro-level expert tutor models such that as a learner progresses through instruction, appropriate information can be continuously sent back to the macro-level to constantly refine the decision making for the succeeding conditions of instruction: In other words, the MAIS employs variables that learn how to improve instructional decision making.

Macro-Level

Figure 1 shows the two main variables of the macro-level component. The variables--cognitive model, affective model, and memory model--represent areas of individual differences within the context of a student model. Research findings have shown that each of these variables have differing effects on learning and, therefore, need constant adjustment based on the curricular knowledge base. The expert tutor is the decision making component of the system. The function of the expert tutor model is to establish the conditions of instruction within the context

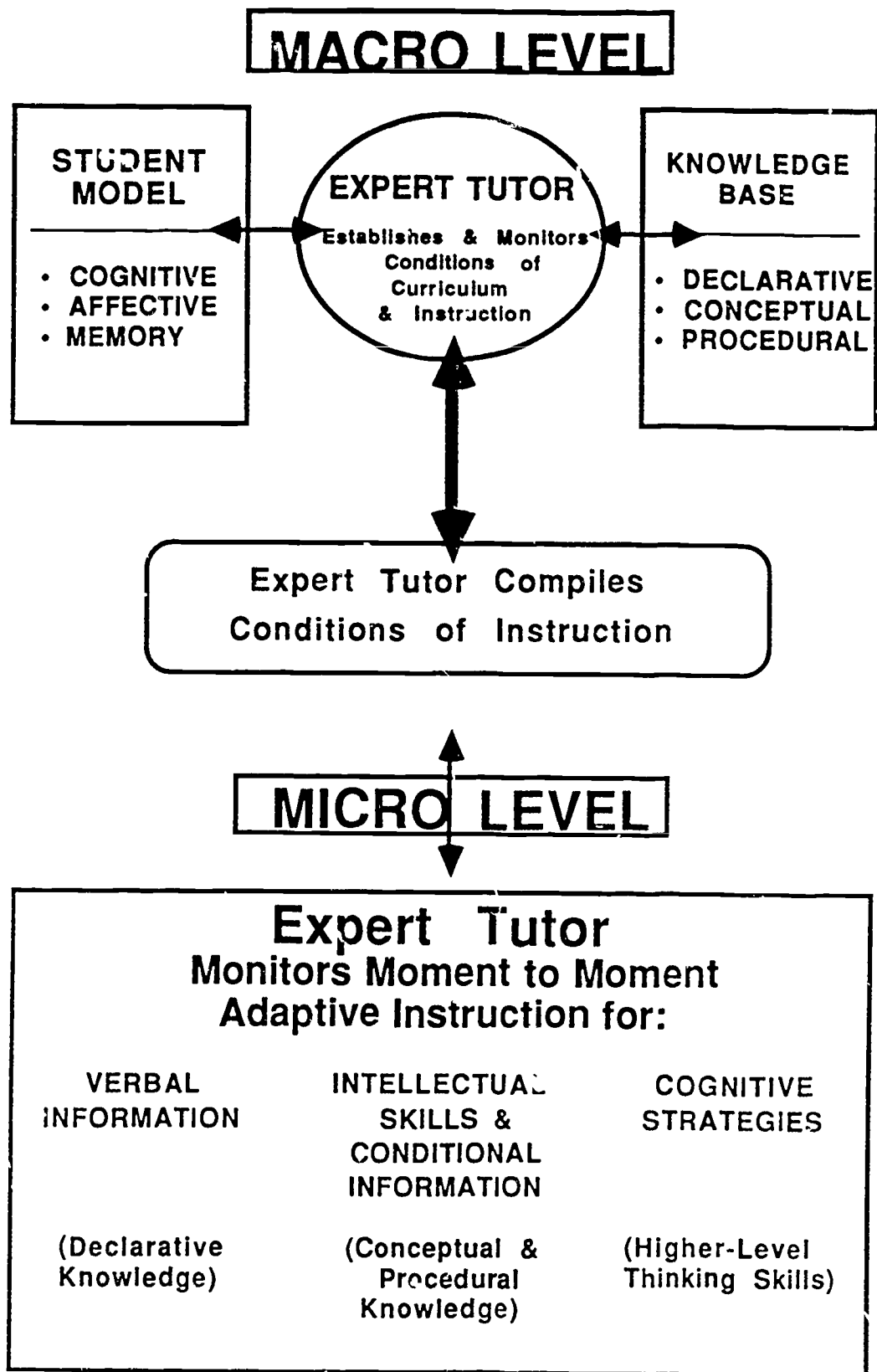


FIGURE 1. Diagram of the MAIS Environment.

of the curriculum. The macro-level expert tutor model compiles the initial parameters of instruction, with the micro-level expert tutor model making necessary adjustments at the moment of learning.

Micro-Level

The instructional level of the MAIS deals directly with student learning at the verbal information, intellectual skills, conditional information, and cognitive strategies objectives of learning. From the nine instructional variables shown in Figure 1, an instructional strategy is compiled from the macro-level expert tutor model. The instructional conditions appropriate for cognitive strategies learning are discussed in an article by Tennyson, Thurlow, and Breuer (in press). Verbal information learning is discussed in Goldberg and Tennyson (1987), therefore, we will also not elaborate here on the unique conditions required for the learning of declarative knowledge. Given the scope of this article, we will discuss our research efforts by focusing only at the intellectual skills/conditional information level of learning objectives. That is, the primary instruction for knowledge acquisition. Cognitive strategies focuses on development and improvement of thinking skills.

Briefly, the nine instructional variables that form the possible meta-instructional strategies for the improvement of knowledge acquisition are as follows (see Figure 1):

- Worked Examples. The learning of complex concepts and rules can be improved if the student understands the underlining principle(s) of the information to be learned. Learning declarative knowledge is the purpose of expository instruction where best examples are presented to show attributes or procedures and the context of the application of the concept's or rule's underlining principles. The computer enhances this form of expository instruction by requiring the student to use input devices to pace the elaboration materials rather than just presenting directly the solution.
- Amount of Information. To improve the efficiency of instruction, the MAIS employs a conditional probability statistic to determine when a student reaches mastery. This variable continuously monitors student progress in learning so as to provide sufficient information for attainment of concept mastery. In cognitive psychology terms, this variable focuses on procedural knowledge development.
- Sequence of Information. In the learning of coordinate concepts and rules, many errors of misconception can by

prevented by the way the information is sequenced. The sequence heuristic of the MAIS is based on the psychological principles of under- and overgeneralization, not a random or branching format favored by conventional ICAI and CAI programs. The sequence heuristic also improves development of a schematic structure in memory so that conceptual knowledge is developed.

- Format of Information. An important principle of good teaching is to engage students as soon as possible in the process of decision making or problem solving. For each student, however, this point in time differs because of the level of knowledge understanding required to solve problems. The purpose of this variable is to monitor the learning need for additional expository information to ensure adequate declarative knowledge formation. Thus, if a student shows during problem solving situations the need for additional declarative understanding, additional expository instruction can be presented.
- Learning Time. An important characteristic of an expert tutor is the ability to monitor student learning in reference to efficient use of time. That is, the tutor knows when to interact with the student so as to provide assistance. For example, when first trying to solve a problem, the student indicates by not responding that they need help, the tutor offers assistance instead of trying to force the student to make a solution and therefore a possible error. The purpose of this variable to be a more active rather than passive computer-based tutor as is typical in conventional ICAI and CAI. This variable is primarily concerned with the formation of conceptual knowledge as contrasted with procedural knowledge development.
- Corrective Error Analysis. Helping the student to understand a mistake is the purpose of this variable. Too often instructional help is not directly related to the learner's specific problem, thus the student is given excessive information which might even mask or hide the learning problem. This is especially the case in learning more complex concepts and rules. In most situations the form of analysis is content specific, however, the important concern is to design a system that can identify possible specific errors rather than the typical CAI method of feedback and branching.
- Mixed Initiative. A major short-coming of technology-based instructional systems is their ability to allow for student questions. With this variable, it is possible for the

student to query the MAIS. For example, if the student does not understand a given procedure or needs an elaboration of some given attribute, they can ask the system. The MAIS then forms a dialogue with the student to understand the student's question. This is another way to help in the formation of conceptual knowledge.

-Advisement. An underlining principle of the MAIS is that the student is making progress in learning towards mastery. Because the student is also involved in various forms of decision making and is putting forth effort in learning, the student needs to be continuously informed of the progress. To accomplish the goal of informing the student of their progress and to even inform them of need, the MAIS advises the student of both their current progress and the necessary instruction to reach mastery. Because this is an adaptive system, changing from moment-to-moment, advisement is provided concurrently with the instructional activities.

-Embedded refreshment and remediation. Learning within a domain of information usually implies making connections between concepts and rules. Most often the learning of connections, and therefore the schematic structure of the domain, is made by the student in memory. However, when the learning of new information requires the connection to prerequisite knowledge and the student cannot retrieve that knowledge, they need help. The purpose of this variable is to sense this need and provide the appropriate help. If the need is only for help in making the connection (i.e., the student knows the prerequisite knowledge), information on the prerequisite knowledge is presented in an expository form at that point. The term embedded refreshment is used to describe this process of helping the student recall the specific prerequisite knowledge at the moment they need to make the connection. If, however, the student needs more than just recall, but needs relearning, remediation is provided.

The expert tutor model at the micro-level adapts continuously the meta-instructional strategy compiled by the macro-level expert tutor. Student learning outcomes are iteratively returned to the macro-level to further enhance the succeeding instruction.

Summary

Our concern in the MAIS research program is not to just develop a prototype system (as in the conventional ICAI research methods of tool making), but to empirically investigate the relationships between the variables of the learner model and how

that relationship, along with the integration with the curricular knowledge base, enhances the instructional strategy decision making at the micro-level. In other words, in contrast to conventional ICAI research which seeks to test software intelligence techniques, we seek to investigate variables that can intelligently improve learning.

We are continuing to investigate a research-based intelligent learning system that can on one hand provide an evaluation of each student (i.e., a highly information rich student model) and, on the other, can be directly associated with the instructional prescription process. We are doing this within the framework of AI methods that will assist in the improvement of the system's inferential ability by adding the concept of system "discovery." That is, the proposed system will not only assess students prior to and continuously during learning, but will also improve its inferential ability by itself learning.

In summary, the MAIS research and development program focuses on the study of intelligent learning systems from an educational research paradigm, with variables and hypotheses directly related to the improvement of learning through the use of adaptive instructional methods. To accomplish this goal, we integrate where appropriate, variables and conditions from a wide range of disciplines and fields of study, including cognitive psychology, developmental psychology, computer science, management information sciences, as well as numerous fields in educational psychology (e.g., evaluation and measurement, reading, and instructional technology and design).

Currently, we know a lot about human learning and, in specific situations, we can actually show how a given variable or condition of instruction can significantly improve certain types of learning. However, the large number of instructional variables and strategies cited in the literature show that learning is a complex phenomenon, requiring more than the generalizable application of one or two strategies. Our research demonstrates that with computer technology, it is now possible to make use of the wide range of instructional variables to develop meta-instructional strategies to improve learning within specific needs. Through the use of AI methods, sophisticated management systems can be developed to make use of the known means to improve learning in cost-effective systems. Our basic research program will extend the work currently being done on the MAIS such that a total, technology-assisted learning system can be designed and tested. It will provide the knowledge base by which current educational and training systems can be adapted and future systems can be designed.

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