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2. KEYNOTE ADDRESS

MAIS: A computer-based integrated instructional system

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An instructional design model, the Minnesota Adaptive Instructional System (MAIS), that links knowledge acquisition and employment with specific computer-based instructional prescriptions is reviewed. Specific cognitive processes for acquisition of declarative, procedural, and contextual knowledge are respectively linked to expository, practice, and problem-oriented strategies. Likewise, the cognitive processes of employment (i.e., recall, problem solving, and creativity) are linked to complex-dynamic and self-directed strategies. Each of the instructional strategies is composed of variables and conditions that have been empirically tested and shown to improve specific forms of knowledge acquisition and employment.

A continuing debate in the field of educational computing is the following two-part question: Does computer-based instruction (CBI) improve learning, and if so, by how much? Those who would answer "yes" base their replies in large part on technocratic assumptions (Kozma, 1991). In addition, this group has most recently received increased support from computer scientists who offer such "new" technologies as interactive video, hypertext, and expert systems (Soloway, 1990).

In contrast, those who would answer "no" base their conclusions on methodological grounds (Clark, 1983, in press). They argue that research findings in favor of CBI have been flawed in both experimental design and methodology. Given the academic approach of their criticisms, such opponents have achieved a hearing only within a limited circle of academically based research programs. In addition, with the rapid development of computer technologies since the application of the microchip in the 1970s, the question of CBI's effectiveness in improving learning seems to have been answered affirmatively. And, given new technologies that offer increasingly broad instructional applications, the academic criticisms continue to be overwhelmed by the popular enthusiasm among the ever-expanding body of users (Kulik & Kulik, 1991).

The debate continues, however, largely because many educators realize that combining existing instructional prescriptions with new delivery systems requires more than mere transfer of those prescriptions to a new context (Wasson, 1992). Also, educational scientists continue to insist on the need to verify empirically the new delivery opportunities offered by new media in the same way as theories are tested. At this point, technologists maintain success in fending off opponents because of new developments in hardware (e.g., interactive video; Locatis, Charuhas, & Banvard, 1990) and software (e.g., hypermedia; Park, 1992). But, as the new technological "solutions" are continually being replaced by even more advanced systems, opponents are still raising the question of CBI's effectiveness in improving learning (Hanfling, in press).

My purpose in this paper is not to answer the question, but to elaborate on it and to offer a view that is both a "yes" and a "no." The problem seems not to be the computer technology itself, but the failure of CBI proponents to adequately link their respective computer-based variables and features to clearly defined improvements in learning. I propose that CBI prescriptions for improved learning should be founded on principles of learning, and that a direct trace between CBI prescriptions and learning should include reference to learning objectives and instructional strategies. This seems necessary, because the distance between the fields of computer-based instructional design and experimental learning theory leaves opportunities for ignoring or disregarding the fundamental importance of application based on theory and empirical verification. Therefore, I shall present an example of a model that I have used in my research on CBI prescriptions; in this way, I intend to demonstrate with some certainty that CBI can be effective in improving learning.

LINKING MODEL

To illustrate the linking of CBI prescriptions to improvements in learning, I will (1) present a model (see Table 1)

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Table 1
Linking Cognitive Processes to Computer-Based Prescriptions

Cognitive Processes	Learning Objectives	Instructional Strategies	Computer-Based Prescriptions: Conventional (Branching)	Computer-Based Prescriptions: Intelligent (Rule-based)
		LEARNING		
Declarative knowledge (knowing what)	Verbal/visual information (being aware of and understanding content—i.e., facts, concepts, rules, and principles and their connections)	Expository Context Label/definition Best example Matched/divergent examples Worked examples	Screen display density Graphics (dynamic)	Advisement Embedded Refreshment and remediation
Procedural knowledge (knowing how)	Intellectual skills (being able to use content with newly encountered problems)	Practice Problem examples Attribute isolation/elaboration Feedback (strategy information)	Tutorial Drill and practice	Amount/sequence of information Learning time Corrective error analysis Process feedback
Contextual knowledge (knowing why, when, and where)	Contextual skills (being capable of content decision making, problem solving, and trouble shooting in complex situations)	Problem-oriented Contextual modules (simulations, case studies, role playing) Cooperative learning	Simulations and virtual reality (modules)	Adaptive error analysis
		THINKING		
Cognitive complexity (differentiation and integration of knowledge)	Cognitive strategies (ability to employ cognitive complexity within novel situations)	Complex-dynamic Situational units (simulations, case studies, role playing) Cooperative learning	Simulations (dynamic: adjusts variables and conditions) Virtual Reality	Elaborates and extends variables and conditions
Cognitive constructivism (creation of knowledge)	Creative processes (ability to construct knowledge within novel situations)	Self-directed experiences	Learner control	Mixed initiative

that links computer-based instructional prescriptions with specific learning outcomes through four main educational components (cognitive processes, learning objectives, instructional strategies, and computer-based prescriptions) (Tennyson & Rasch, 1988) and (2) discuss the linking model in terms of findings from a specific computer-based instructional research program—the Minnesota Adaptive Instructional System (MAIS), which provides a rich source of information for this purpose (Tennyson, 1984, 1987, 1990a, 1990b; Tennyson & Christensen, 1988; Tennyson, Christensen, & Park, 1984).

The linking model (see Table 1) that I am proposing should help one understand why certain CBI variables might improve learning and should also encourage computer-based instructional designers and researchers to look beyond the technology to determine new, effective computer developments. I propose that CBI can improve learning when it is viewed as an integral component of the entire instructional design. The model indicates a direct interactive link between specific computer-based instructional prescriptions and basic foundations of cognitive learning theory.

Components of the Linking Model

I will now discuss the four components of the linking model, beginning with a summary of an educational learning model that I have employed in the MAIS research program (for a more complete discussion see Tennyson, 1992). Following that brief presentation, I present the next component, learning objectives, employing a modified version of Gagné's (1985) hierarchy of learning conditions. Components three, instructional strategies, and four, computer-based prescriptions of the hierarchy, are taken directly from my own research program on instructional strategies and computer-based enhancements of those strategies.

Cognitive Processes. Here, I will limit my discussion of cognitive processes to those associated with knowledge acquisition and employment (Tennyson, 1992). The term *knowledge acquisition* refers to the learning of content and cognitive skills. *Content* refers not only to a given domain's facts, concepts, rules, and principles but also to the meaningful connections of those elements (i.e., declarative knowledge). Cognitive skills are domain-specific cognitive strategies associated with knowing how to use content with newly encountered problems (i.e., procedural knowledge) and knowing the conditions (i.e., why, when, and where) under which content is used in complex problem situations (i.e., contextual knowledge; see Tennyson, in press). *Employment of knowledge* refers to the thinking abilities of cognitive complexity (i.e., differentiation and integration of knowledge; Tennyson & Breuer, 1984) and cognitive constructivism (i.e., creating knowledge; Tennyson & Breuer, 1993). These three aspects of content, skills, and strategies make up what is referred to as *long-term memory*. Content is usually defined as consisting of declarative knowledge, whereas cognitive skill implies procedural and contextual knowledge; together, the three kinds of knowledge form a learner's knowledge base. Cognitive strategies are the cognitive processes of differentiation, integration, and construction.

Learning objectives. A main goal of education and training is the promotion of objectives to improve learners' acquisition and employment of knowledge. Objectives are necessary for one to be able to identify the type of learning and thinking that is appropriate in each instructional situation. Thus, objectives should be linked to specific learning processes. The learning objectives listed in Table 1 are linked to the two cognitive processes as follows: In the learning category, the objectives include the acquisition of verbal/visual information, intellectual skills, and contextual skills; in the thinking category, the objectives include the elaboration and improvement of cognitive strategies and the development of creative processes. The labels used here are modified from Gagné's (1985) hierarchy of learning conditions.

Instructional strategies. The means of instruction are the variables and conditions manipulated by the instructional designer to improve learning. In Table 1, I present basic variables that have been empirically tested to see whether they improve learning. The variables are directly linked to their respective primary cognitive processes. Certain variables may also have secondary links to other processes. The instructional variables are organized into five primary strategies: expository, practice, problem-oriented, complex-dynamic, and self-directed experiences.

Computer-based prescriptions. The computer-based prescriptions listed in Table 1 are subdivided into categories according to the programming and design methods appropriate for adapting instruction to individuals' learning needs. Conventional CBI programming methods involve the use of branching techniques that are determined in the design stage and are preset in the program. In intelligent CBI methods, rule-based programs instruct the learner by making decisions that are based on a model of the learner's cumulative record of learning progress and immediate instructional need. Thus, the instruction is uniquely adjusted from moment to moment, on the basis of real-time assessments made during learning (Tennyson & Park, 1987). Intelligent CBI offers dynamic adaptive instruction, in contrast with the static instruction of conventional CBI.

Linking Components

In this section, I shall illustrate the direct links between the four components which make it possible to trace a specific computer-based prescription variable to a given cognitive process. In this way, I can predict a given learning outcome from the employment of a specific CBI prescription.

Linking declarative knowledge. Declarative knowledge is the foundation of content and implies "knowing what." For example, the student knows the definition of a given concept and knows the connections of the concept within the domain. The learning objective states that the student must learn the verbal and visual information about the domain (i.e., the content [facts, concepts, rules and principles] and the structure of the domain).

According to cognitive theory, visual information may be represented in memory differently from verbal information (Rasco, Tennyson, & Boutwell, 1975). In terms of objectives, this implies not only the use of visual information during instruction, but also the recognition that certain information is primarily visual. For example, the student is aware that certain geometric shapes represent structural strength, but that others represent perceptual illusions.

Learning objectives are usually stated to reflect learning outcomes, so they serve the purpose of identifying the appropriate instructional strategy and the type of performance for evaluation. In Table 1, specific instructional variables and conditions prescribed for declarative knowledge acquisition are listed under the expository instructional strategy category. The objectives for employment of declarative knowledge are embedded within higher order cognitive activities. Certainly, automatic performance is desirable, but within the context of higher order processing. Objectives that only imply acquisition of declarative knowledge are rarely suitable for most learning situations.

The instructional strategy for improving declarative knowledge includes variables and conditions directed at (1) extending and elaborating current knowledge and (2) the acquisition of entirely new domains of information. If it is assumed or known that the learner is extending and/or elaborating on his/her current knowledge, the instructional strategy can proceed to the problem-oriented strategy category (Tennyson & Bagley, 1992). For the learning of a new domain of information, a more structured approach to learning must be developed. The remaining discussion of declarative knowledge treats the acquisition of information in a new domain rather than the extension of knowledge.

The five expository variables can either be shaped into a conventional CBI program or be embellished with techniques of intelligent rule-based enhancements. To introduce learners to new domains of information, a contextual basis for the information must be established. Contexts require learners to draw on abstract knowledge connected with everyday situations. A context can be considered a scenario in which the learner understands the situation (Tennyson, Elmore, & Snyder, 1992).

The selection of the other four variables is based on the complexity of the information. For example, if the information is of low complexity, a simple definition is all that is needed. However, if the information is complex, numerous examples may be necessary. A best example represents a clear case of the concept (or rule or principle). Additional examples should reflect the scope of the concept (matched examples) and diversity (divergent examples). In situations where the concept is conditional, worked examples may be necessary (see Tennyson & Cocchiarella, 1986, for a complete review of these instructional variables).

Computer-based enhancements for conventional CBI are concerned with the screen display of both text and graphics (Morrison, Ross, O'Dell, & Schultz, 1988). Although a discussion of these aspects is beyond the scope of this paper, it should be noted that the graphics capabilities of contemporary computers facilitate improved learning of visual information (Levin, Anglin, & Carney, 1987). In the past, graphics were considered an adjunct to texts (Levin & Lesgold, 1978); now, it is possible to consider graphics as a main source of presentation.

The intelligent CBI variables provide a means to inform learners of their learning progress and instructional needs (i.e., advisement) so they can participate in the management of their own learning (Tennyson, 1981). Conventional (i.e., branching) CBI can accommodate learners' control only by predetermined menu options. The other variable, embedded instruction, implies that the program's management system evaluates the learner's need for help either in making connections with his/her existing knowledge or in learning necessary information not already in memory (Park & Tennyson, 1986). Thus, in the intelligent component, the instructional system goes beyond the passive expository presentation of information.

Linking procedural knowledge. Procedural knowledge is the cognitive skill of "knowing how" to use content to solve newly encountered problems (Tennyson, Welsh, & Christensen, 1985). The learning objective refers to this process as an intellectual skill, in which the students learn how to use specific content facts, concepts, rules, and principles to solve previously unencountered problems. For example, the student learns how to use concepts of experimental design that are necessary for conducting studies in educational research.

The primary instructional variables at this level focus on the practical use of the information to solve problems. As with expository examples, practice examples should be selected to provide a wide range of applications. Divergent examples (i.e., examples that have different irrelevant features) allow the students to elaborate on their declarative knowledge.

To help students learn how to use content, practice problems should provide information that illustrates the required skill through the isolation and elaboration of attributes. That is, once the student is shown examples of solved problems and once the student has attempted to solve practice problems, the various steps or components of the process (as demonstrated in the examples) can be isolated and/or elaborated on. Thus, instead of the simple evaluation of an answer, isolation or elaboration helps the student understand how a given concept works (Tennyson, Park, & Christensen, 1985).

Another instructional variable for practice is feedback on the cognitive skill required to solve problems associated with the information being learned. Feedback presents strategy information following the attribution isolation/elaboration information. The purpose is first to help the learners with solving the given problem, and then to help them form intellectual skills that will be useful in attempts to solve additional problems (Tennyson, Steve, & Boutwell, 1975).

Tutorial instructional strategies provide a convenient method of interaction between the student and the tutor, be it either a human peer tutor or a computerized tutor. The basic format is question/answer, with the tutor challenging the student to use the skill. However, the main purpose of a tutor is to prevent or eliminate possible misconceptions. While the tutorial strategy focuses on intellectual skill acquisition, drill and practice strategies are useful to help develop automatic behaviors for either content or skills. By *automatic*, I mean more than just efficient processing but, additionally, correct behavior whenever activated by a cognitive strategy. For example, complex situations that require manipulation and recall demand that the individual respond in automatic fashion without delay or interference.

It is within this tutorial instructional strategy that the most dramatic advances in CBI have been made in the last two decades. The variables listed in Table 1 are, in part, taken from our research program on the MAIS (Minnesota Adaptive Instructional System; Tennyson & Christensen, 1988). The MAIS is an intelligent instructional system that incorporates expert tutorial techniques in monitoring student learning. Variables monitored by the MAIS include the amount of information, learning time, sequence of information, feedback, and corrective error analysis. Most of the intelligent enhancements are found in various forms in many of the intelligent-based CAI systems (Tennyson & Park, 1987). Additionally, all of the listed enhancements have been empirically tested in both laboratory and applied environments.

An important operational feature of intelligent CBI systems is the development of a student model that exhibits the current knowledge base of the student. More recent student modeling techniques have included affective aspects of the student as well as cognitive ones (Tennyson & Park, 1987). Additionally, intelligent systems have extensive built-in domain-based knowledge bases to allow for students' queries during instruction.

Linking contextual knowledge. This cognitive process refers to the knowledge associated with the skills of "why, when, and where." For example, the student knows the criteria necessary to select different types of statistical strategies for evaluating curricular programs. The learning objective—contextual skills—implies being able to perceive the criteria for, values of, and/or appropriateness of using facts, concepts, rules, and principles within complex situations. Additionally, contextual skill represents in the knowledge base the rules that govern the connections for the content in the domain. Contextual skills are activated by the cognitive strategies and creative processes when engaged in higher order cognitive situations. Without contextual skills, complex decision making, problem solving, and trouble shooting would not be possible (Tennyson & Breuer, 1991).

The instructional strategy variables for learning this cognitive process help students learn the necessary cognitive skills to use the knowledge base in complex situations. The task for the instructional designer is to develop an environment that exhibits a meaningful context. The learning context can be of several types, including simulations, case studies, role playing, and other situations that require the student to use declarative and procedural knowledge in necessarily complex situations.

In learning situations that include objectives for improvements in cognitive thinking processes, the context could be the same as it is in the complex-dynamic strategy, the difference being that the larger context (i.e., situational units; see Table 1) needs to be divided into contextual modules (Tennyson et al., 1992). For example, if a simulation is employed as the instructional learning environment, the domain is divided into modules that cluster the concepts. In this way, the student is learning contextual knowledge in manageable clusters, based in part on conceptual connections. All the clusters are integrated for use within the complex-dynamic strategy.

Problem-oriented contextual modules present problem situations that require the student to analyze the situation, work out a conceptualization of the situation, define specific goals for coping with the situation, and propose a solution or decision. Unlike problems in the practice strategies that focus on the acquisition of procedural knowledge, problem-oriented contextual modules present situations that require employment of the domain's declarative and procedural knowledge. Thus, the student is in a problem-solving situation that requires establishing connections and associations among the facts, concepts, rules, and principles of specific domains of information (Tennyson, Thurlow, & Breuer, 1987).

Cooperative learning group techniques provide additional means of improving contextual knowledge acquisition by allowing students to develop solutions and see alternative solutions to contextual problem-oriented situations. Within groups, the students work toward a specific goal by using their respective abilities and aptitudes and, by doing so, improve their understanding of the criteria, values, and appropriateness of knowing why, when, and where to employ knowledge. The problem-oriented strategy allows students to work on situations that require the use of the knowledge they are acquiring. Such use requires them to make decisions about knowledge selection and organization and, by working in a group, see how their ideas relate to the others'.

Computer-based simulations have long been used as instructional means to present contextual situations (Tennyson, 1974). More recently, research in intelligent systems has offered techniques for adjusting the variables and conditions of the situation on the basis of error analysis. Adaptation of the context to students' learning needs addresses possible misconceptions directly as well as focuses on missing information in the student's knowledge base (Tennyson, 1990a).

Further computer-based advancements offer enhanced simulations by means of virtual reality techniques. Whereas current graphic displays are two-dimensional, virtual reality provides for three-dimensional displays. Additional techniques include manipulative devices that integrate cognitive activities with physical features. Virtual reality is especially useful in domains that involve spatial and psychomotor aspects of knowledge representation (Tennyson & Breuer, 1993).

Linking cognitive complexity. Most often, cognitive theories of learning focus on knowledge acquisition while basically ignoring employment of knowledge in the service of thinking (i.e., recall, problem solving, and creativity). However, an important goal of education and training includes not only acquisition of knowledge, but also the improvement and employment of knowledge. Improvement implies both extension and elaboration of current knowledge. Cognitive retrieval system theory indicates that thinking skills and strategies develop most adequately when one is working concurrently with the knowledge base.

Complex-dynamic strategies require students to employ their knowledge in the generation of solutions to complex, dynamic problems (Breuer & Davidson, 1989; Breuer & Kummer, 1990; Salomon, Perkins, & Globerson, 1991). Such learning processes are expected to improve the cognitive abilities of students (i.e., differentiation and integration; see Table 1).

Five basic features should be considered in the design of situational units for improvement in cognitive complexity:

1. The context should be meaningful and interesting to the student.
2. The context should permit the student to generate information through his/her own knowledge base search efforts and to employ this knowledge in proposing solutions, decisions, and so forth.
3. The context should provide a responsive, changing environment in which the student can receive feedback relevant to his/her evolving cognitive strategies.
4. The context should permit the student to move from knowledge employment and improvement to knowledge acquisition, back to knowledge employment, and so on. This movement from one process (employment) to another (acquisition), from the employment of discrepant information to the combination of information in cognitive strategies, helps overcome boredom and creates interest in learning.
5. The context should measure the degree of cognitive strategy employed independently of the knowledge acquisition.

In the MAIS research programs, we have developed situational units (i.e., complex-dynamic simulations) within domains such as politics and economics. In our designs, each simulation starts from a complex scenario that allows individual information searches and decision-making processes. The simulations are responsive in that they reflect the decision-making processes of students by changing the status of the variables and conditions that represent the situation. The simulations are open-ended—all decisions entered initiate a different and usually a new status of the depicted situation, which can be "improved" or "optimized" by the student again. The simulation is designed to encourage steady involvement of students and the repeated need for movement between knowledge and cognitive strategies. Additionally, cognitive activity can be further enhanced within cooperative learning groups, through the use of cognitive activities such as explanation, argument, justification, and adaptation for the individuals as they interact with group partners.

The computer-based prescriptions enhance the instruction by providing a dynamic environment. Computer-based simulations, for example, can continuously adjust and modify the situation. Intelligent systems would base the adjustments on the student model. This is useful for tracking student's knowledge acquisition in the cognitive process of integration. Also, the techniques of virtual reality would contribute in domains exhibiting three-dimensional knowledge representation.

Linking cognitive constructivism. An important goal of education is the development of learners who can be responsible not only for employing their existing knowledge but also for creating new knowledge. One initial concern of cognitive theory (e.g., Bartlett, 1932; Spiro, 1977), in contrast with behavioral theory, was the ability of the learner to create or construct knowledge. An assumption was that all knowledge in the external world was an artificial representation and that domain experts were responsible for translating knowledge into acceptable external representations. Representation ranged from highly structured and concrete representations to widely divergent and abstract representations. Accordingly, the purpose of this instructional strategy category is to provide an environment in which students have defined opportunities to improve their cognitive abilities to construct new knowledge.

For the most part, this process of cognitive constructivism can be improved by instruction that is self-directed (Tennyson & Bagley, 1992)—that is, a learning environment rich in resources and time for the student to seek answers to both predefined and self-defined problems. Although cognitive constructivism may occur in unplanned environments, planned instructional environments can help create spheres of domain focus. For example, in the area of social studies, the environment might include resources that would benefit creation of knowledge in that area in contrast with domains in the physical sciences.

Research in writing has led to improvement in basic writing skills as well as creativity through the use of computer-based word-processing systems (Reed, 1992). In less planned environments, such as computer-based interactive games, it has been found that individuals create the knowledge necessary to continue improving their performance. Computer-based enhancements provide rich facilities that are under the student's control and, with intelligent systems, allow students to query the system. A mixed-initiative learning environment simulates the interaction between a domain expert and a novice learner. Thus, the student can artificially alter the time needed to create new knowledge. Interest in virtual reality techniques is especially high in this area of cognitive processing because of the total landscape of the artificial environment.

Students may have the opportunity to explore just about any avenue of the domain without constraints that may be inherent in the real environment (Tennyson, 1990b).

SUMMARY

I have presented an example of a means by which educators can determine whether specific instructional strategies and corresponding computer-based variables and methods may improve learning and thinking. I have not attempted to debate whether or not CBI improves learning. Rather, I have been proposing that computer-based prescription is but one component in a complex instructional design system that includes principles of instructional design as well as methods of instructional delivery. For an instructional method to improve learning, the method must have two aspects. First, it must exhibit a direct link to a specific cognitive process. And second, it must have empirical support to confirm the prediction that learning can be improved by its application.

With the expansion of electronic media, it becomes increasingly important that direct linkage to cognitive processes, including both acquisition and employment, be maintained in instructional design. For example, the use of animation is expanding in CBI but actual empirical findings have failed to confirm reliable differences between dynamic and static visual displays (Park & Gittelman, 1992). In the learning industry, the means of linking advancements in media to instruction are available and should be considered whenever one is designing learning environments.

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