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ABSTRACT

This paper discusses two related areas *in* which recent advancements *in* cognitive science and Educational technology may affect instructional design theory. These are= (1) the analysis of information-to-be-learned; and (2) the linkage of learning theory to instructional prescriptions. The first area proposes extensions to current methods of content/task analysis procedures. Contextual module analysis proposes an additional analysis of the information based upon complex problems associated with a given situation. Whereas conventional content and task analyses identify the attributes of the information, the contextual module analysis identifies the organization and accessibility of the information in reference to a given situation. The second area proposes the framework for an instructional design model that links cognitive learning theories with specific educational strategies. Rather than acquisition of knowledge in nonsense isolation, it is proposed that learners acquire knowledge within meaningful situations. Research in instructional design theory has focused on strategies associated with declarative and procedural knowledge with minimal empirical work for strategies associated with contextP.al knowledge. Instructional technology should provide the means by which cognitive science can be applied to improvements in learning. (31 references) (DB)

Advancements in Instructional Design Theory: Contextual Module Analysis and Integrated Instructional Strategies

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Advancements in Instructional Design Theory: Contextual Module Analysis and Integrated Instructional Strategies

Scientific advancements in cognitive science and instructional technology suggest significant changes in methods of curricular and instructional design which will strongly affect educational practice (Tennyson, 1990b). These advancements extend the predominantly applied behaviorally-oriented learning paradigm of instructional design and management (Case & Bereiter, 1984). In this paper we will discuss two major areas in which cognitive science and instructional technology are affecting instructional design (ID) theory. These are: (a) the analysis of the information-to-be--learned and, (b) the linkage of learning theory to instructional prescriptions.

Analysis of Information-to-be-Learned

An important component of ID models is the analysis of the information-to-be-learned. Two basic types of analyses include: (a) a content analysis, that focuses on defining the critical features of the information and the relationship of those features according to superordinate and subordinate organizations; and (b) a task analysis, that focuses on a hierarchical organization of the information based on prerequisites. Both of these analyses identify the external structure of the information but do so independent of how it might actually be s tored in human memory. However, research in cognitive psychology on human memory suggests that the internal organization of information in a knowledge base is based more unemployment needs than by attribute or hierarchical associations (Fodor, 1983). That is, the utility of the knowledge base is attributed to its situational organization not the amount of information. The implication of knowledge base organization is the need for a further analysis of the information to better understand the possible internal organization of the information (Garner, 1990). Better organization in memory may also imply better accessibility within the knowledge base for such higher order cognitive activities as problem solving and creativity (Harre, 1984).

To understand the nature of knowledge base organization, cognitive psychologists analyze problem complexity and the way individuals try to solve given problems (Klahr, Langley, & Neches, 1987). By analyzing problems it is possible to identify the concepts employed; and, by analyzing the solutions, it is possible to identify the associations of those concepts within given problem situations. The implication for ID theory is that the sequence of information for instruction should be based in part on internal situational associations as well as external structures (Bereiter, 1990). The assumption is that because external structures are independent of employment needs, an analysis of possible internal associations would irnprove the initial organization of the new information, resulting in better employment.

In addition to the analyzing of problems and solutions, is the issue of problem situation or context (Mishler, 1979). For example, expert systems reside within the constraints of a specific context: That is, they can solve problems only associated with that given context (Newman, Griffin, & Cole, 1989). Likewise, research in cognitive psychology shows that individuals can solve complex-problems only if they poses the necessary contextual knowledge (i.e., knowledge of when and why) (Tennyson, 1990d). For example, the objective in learning to play chess is the learning of problem solving strategies within the context of both the given game and the current move: not just how the various chess pieces move (i.e., procedural knowledge). Thus, the key to both effective acquisition and employment of knowledge is the organization of the information according to contextual applications. That is, contextual knowledge includes not only information (i.e., content/task) but also the cultural aspects directly associated with that information (Brown, Collins, & Duguid, 1989). Cultural implies the selection criteria, values, feelings and appropriateness associated with the information of given contextual situations.

The extension for a content/task analysis suggested by cognitive science is the method employed for an information analysis. In addition to the conventional content and task analyses, a context analysis is proposed if the goal of the instruction includes employment and improvement of cognitive skills and strategies, such as problem solving, decision making, and trouble shooting. Basic steps for a contextual module analysis are as follows:

- Define the context for the employment of the information-to-be- learned. A context is meaningful application of the information (i.e., the complexity of the situation including the content/task, skills, goals, and culture) (Lawler, 1985).
- Define the complex-problems associated with the context. This step follows a knowledge engineering approach where problems associated with the context are identified (Laird, Newell, & Rosenbloom, 1987).
- Analyze problems to identify concepts, principles, rules, or facts employed.
- Analyze the concepts, etc. to determine their associations and connections. This provides for the overall organization of the module. This analysis should include as much as possible the when and why aspects of the information employment. This is the initial information to help form the culture of the knowledge base (Fodor&: Pylshyn, 1988).
- Within the module, identify possible clusters of concepts employed in the solution of the various problems.
- Sequence the clusters into instructional components, by grouping problems according to shared concepts.

- Analyzing problems within a context and then identifying the concepts and their employment organization provides a means for sequencing the instruction to improve higher order cognition. In other words, the sequence of the instruction is based on the objective of improving employment of knowledge in addition to improvements in acquisition.

Example of a Contextual Module Analysis

The following example is presented to illustrate the above defined procedures for a contextual module analysis. The example is taken from our research program using business management principles as the content domain. The project used a contextual module analysis to design an instructional program to improve problem-solving in an operations management environment. The example will follow the steps defined above.

Step 1: Define the context.
Using a simulation for the management of a kitchen cabinet factory, the student makes operational decisions which affect the profit or loss of the company. Based on the contextual module analysis, three instructional modules w re developed to prepare the student to solve problems commonly encountered during the simulation.

Step 2: Define the complex problems.
Using a knowledge engineering approach, problems were identified as representative of the situations encountered in the management of the factory, The problems were then rank-ordered by complexity; complexity being determined by the number of relevant principles required to solve the problem.

Step 3: Analyze the problems.
Initially there were a large number of problems identified. After assigning principles to each problem, many of the problems were dropped from the list because the particular grouping of principles involved was already related to another problem. The remaining smaller group (ten problems) was then determined to represent the knowledge necessary to manage the factory. Relevant principles were identified for each problem. More complex problems required more principles to be employed in the solution of the problem and most of the principles were used in the solution of several problems.

Step 4: Organize information into a module.
Figure 1 illustrates the grouping of problems by their associated principles. The instructional design focuses on related principles for specific problems and on shared principles which provide context for problems. That is, for each specific problem the focus is on the related principles used to solve the problem and their relationships. Principles

which are used for several problems (shared principles) provide more context for the problems. As shown in Figure 1, the principles required to solve a problem are grouped according to their association.

Step 5: Sequence clusters into instructional components.

Figure 2 shows the ten problems divided into three instructional components or units. As you can see from Figure 2, the problems in the first two units are less complex, yet most of the principles are being introduced for the first time in these problems. The problems in unit three are more complex, but all the principles except one have been used in previous problems.

Module	Problem	Principles
Module 1	Wages too low or too high	A - Wage effects on productivity
Module 1	Innappropriate rate of advertising	B - Role of advertising C - Demand D - Market Saturation
Module 1	Machine maintenance	E - Replacement of older machines F - Optimum level of repair
Module 2	Ir ppropriate number of machines	G - Production goals H - Number of workers I - Machine types
Module 2	Raw materials not available or price too high	G - Production goals J - Inventory K - Raw material orders L - Price differences of raw material orders
Module 2	Inappropriate number of workers	G - Production goals M - Number of machines

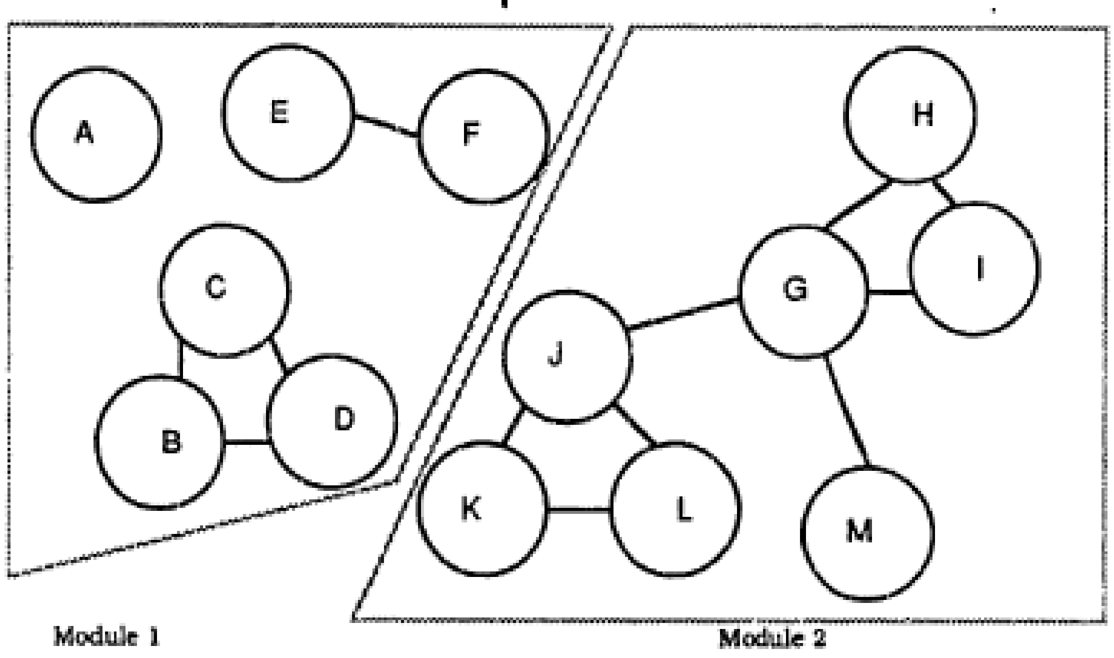

Figure 1. Problems grouped by associated principles

Module	Problem	Principles
Module 1	Wages too low or too high	A - Wage effects on productivity
Module 1	Inappropriate rate of advertising	B - Role of advertising C - Demand D - Market Saturation
Module 1	Machine maintenance	E - Replacement of older machines F - Optimum level of repair
Module 2	Inappropriate number of machines	G - Production goals H - Number of workers I - Machine types
Module 2	Raw materials not available or price too high	G - Production goals J - Inventory K - Raw material orders L - Price differences of raw material orders
Module 2	Inappropriate number of workers	G - Production goals M - Number of machines
Module 3	Production capacity not consistent with demand	F - Optimum level of repair G - Production goals H - Number of workers I - Machine types M - Number of machines
Module 3	Production and inventory not consistent with demand	B - Role of advertising G - Production goals H - Number of workers J - Inventory M - Number of machines N - Selling price
Module 3	Raw materials on hand not consistent with production goals	G - Production goals H - Number of workers K - Raw material orders L - Price differences of raw material orders M - Number of machines N - Selling price
Module 3	Demand is too low	B- Role of advertising D - Market saturation N - Price

Figure 2. Module organization by associated principles

Integrated Instructional Strategies

In this section we present a second area of cognitive science and instructional technology influences on 10 theory. For the purposes of this paper, we are only dealing with the development of an instructional design model that focuses on the planning of a learning environment so that students improve their acquisition of knowledge. In Figure 3, we present an instructional design model that shows the direct integration of cognitive learning theory with prescribed instructional strategies (Tennyson, 1990c). The major components of the ID model are: memory systems, learning objectives, and instructional prescriptions. These are now discussed in turn.

ID Components	Acquisition of Knowledge Base		
Memory Systems	Declarative Knowledge	Procedural Knowledge	Contextual Knowledge
Learning Objectives	Verbal Information	Intellectual Skills	Contextual Skills
Instructional Prescriptions	Expository Strategies	Practice Strategies	Problem-Oriented Strategies

Figure 3. Instructional design model linking cognitive learning theory with instructional prescriptions.

Memory Systems.

The proposed ID model is directly associated to a cognitive paradigm of learning. (This paradigm is presented in Tennyson, 1990d.) Because the purpose of this paper is with improvement in acquisition of knowledge, only the storage system of long-term memory is discussed. (In other papers, improvements in employment of knowledge are presented: e.g., Tennyson & Breuer, in press). The storage system is composed of three basic forms of knowledge: Declarative knowledge, knowing that" about the information; procedural knowledge, knowing "how" to use information (Anderson, 1987); and, contextual knowledge, knowing "when and why" to use given information.

Proposed in the ID model (see Figure 3) is that there is a direct connection between the three basic types of knowledge and prescribed instructional strategies. The purpose for including this component in the ID model is twofold: First, to establish a direct linkage between instructional theory and learning theory: This was done successfully with the behavioral paradigm where instructional strategies were designed following the conditions of that paradigm. Therefore, we have attempted in this paper to make an association between the cognitive paradigm and instructional strategies. And, second, to indicate the relative strengths of the instructional strategies in reference to f. types of knowledge. Within the proposed ID model, the learning objectives tie directly the memory systems components with the instructional prescriptions.

Learning Objecctives.

The purpose of cognitive-based learning objectives is to further elaborate the curricular goal of knowledge acquisition. Objectives are important in the planning of learning environments because they provide the means for identifying specific instructional strategies. We define learning objectives as follows:

> Verbal information. This objective deals with the learner acquiring an awareness and understanding of the concepts, rules, and principles within a specified domain of information (i.e., declarative knowledge).
>
> Intellectual skills. This objective involves the learner acquiring the skill to correctly use the concepts, rules, and principles of a specified domain of information (i.e., procedural knowledge).
>
> Contextual Skills. This objective focuses on the learner's acquisition of a knowledge base's organization and accessibility (i.e., contextual knowledge). *The* organization of a knowledge base refers to the modular structure of the information whereas the accessibility refers to the executive control strategies that provide the means necessary to employ the knowledge base in the service of recall, problem solving, and creativity (Fodor, 1985}. Contextual knowledge includes the criteria, values, feelings, and appropriateness of a given domains modular structure. For example, simply knowing how to classify examples or knowing how to use a rule (or principle) does not imply that the learner knows when and why to employ specific concepts or rules.

Instructional Prescriptions.

The purpose of the proposed ID model is the direct linkage of instructional strategies to specific memory system components (Tennyson & Rasch, 1988). Also, instead of prescribing a given strategy of instruction for all forms of learning, we have identified general categories of strategies, each composed of variables and conditions that can be manipulated according to given instructional situations (Tennyson, 1988).

The three instructional strategy categories are as follows:

Expository strategies.

This category represents those instructional variables designed to provide an environment for learning of declarative knowledge (see Figure 3). The basic instructional variables provide a context for the to-be-learned information. That is, the concept of advance organizers is extended by presenting a meaningful context for the information as well as a mental framework of the given domains abstract structure. In addition to providing a context for the information, meaning can be further enhanced by adapting the context to individual student background knowledge (Ross, 1983). The context establishes not only the initial organization of the domain but, also, introduces both the "why" of the theoretical nature of the information and the "when" of the criterion nature of the domains standards, values, and appropriateness (Bereiter & Scardamalia, 1989). Personalizing the context to student background knowledge improves understanding of the information by connecting, within working memory, knowledge that is easily retrieved. Thus, the new knowledge becomes directly linked or associated with existing knowledge base modules.

Following the contextual introduction of the information, additional expository instructional variables present the ideas, concepts, principles, rules, facts, eh.:. in forms that extend existing knowledge and that aid in establishing new knowledge. These variables include:

> Label. Although a simple variable, it is often necessary to elaborate on a label's origin so that the student is just not trying to memorize a nonsense word.
>
> Definition. The purpose of a definition is to link up the new information with existing knowledge in long-term memory; otherwise the definition may convey no meaning. That is, the student should know the critical attributes of the concept. To further improve understanding of the new information, definitions may, in addition to presentation of the critical attributes (i.e., prerequisite knowledge) include information linked to the student's background knowledge.
>
> Best Example. To help students establish clear abstracts of a domain's concepts, an initial example should represent an easy comprehension of the given concept (or rule, principle, idea, etc.). Additional expository examples will enhance the depth of understanding.

Expository Examples. Additional examples should provide increasingly divergent applications of the information; perhaps also in alternative contexts).

Worked Examples. This variable provides an expository environment in which the information is presented to the student in statement forms that elaborate application. The purpose is to help the student in becoming aware of the application of the information within the given context(s). For example, to learn a mathematical operation, the student can be presented the steps of the process in an expository problem while, concurrently, presenting explanations for each step. In this way, the student may more clearly understand the procedures of the mathematical operation without developing possible misconceptions or overgeneralizations.

Practice strategies.

This category of instructional prescriptions contains a rich variety of variables and conditions which can be designed into numerous strategies to improve learning of procedural knowledge. This category is labeled practice, because the objective is to learn how to use procedural knowledge correctly; therefore, it requires .constant interaction between student learning (e.g., problem solving) and instructional system monitoring (Tennyson &t Park, 1987). Practice strategies should attempt to create an environment in which (a) the student learns to apply procedural knowledge to previously un-encountered situations while (b) the instructional system carefully monitors the student's performance so as to both prevent and correct possible misconceptions of procedural knowledge.

The basic instructional variable in this strategy is the presentation of problems that have not been previously encountered (see Tennyson & Cocchiarella, 1986, for a complete review of variables in this category). Other variables include means for evaluation of learner responses (e.g., pattern recognition), advisement (or coaching), elaboration of basic information (e.g., text density, Morrison et al., 1988), format of information, number of problems, use of expository information, error analysis, and lastly, refreshment and remediation of prerequisite information.

Problem-oriented strategies.

A proposed instructional strategy for this category uses problem-oriented simulation techniques. The purpose of simulation is to improve the organization and accessibility of information within a knowledge base by presenting problems that require the student to search through their memory to locate and retrieve the appropriate knowledge to propose a solution.

Within this context, the simulation is a problem rather than an expository demonstration of some situation or phenomenon (Breuer & Kumrner, 1990).

Problem-oriented simulations present domain specific problem situations to improve the organization and accessibility of information within the knowledge base. Basically, the strategy focuses on the students trying to use their declarative and procedural knowledge in solving domain-specific problems. Problem-oriented simulations present problem situations that require the student to (a) analyze the problem, (b) work out a conceptualization of the problem, (c) define specific goals for coping with the problem, and (d) propose a solution or decision. Unlike problems in the practice strategies that focus on acquiring procedural knowledge, problem-oriented simulations present situations that require employment of the domain's procedural knowledge. Thus, the student is in a problem solving situation that requires establishing connections and associations (i.e., cultural aspects) among the facts, concepts, rules, and principles of specific domains of information.

Example of Integrated Instructional Strategy

In the extending the example from the business management project, the instruction is presented in three instructional units; organized by clustering problems sharing common principles. The number of instructional units was determined by the number of problem sets which could be identified by their common principles. The instruction is presented by (a) establishing the sub-context for the content in each module, (b) presenting the concepts in an expository manner with practice problems employing the principles in a limited context, and (c) providing a problem-oriented simulation limited to the problems and principles presented in that unit.

The instructional program was developed using the PCD3 authoring system, which uses icons to illustrate the overall instructional design. Figure 4 shows the structure of unit 1, in which the material is presented first in an expository manner, with worked examples, followed by practice problems.

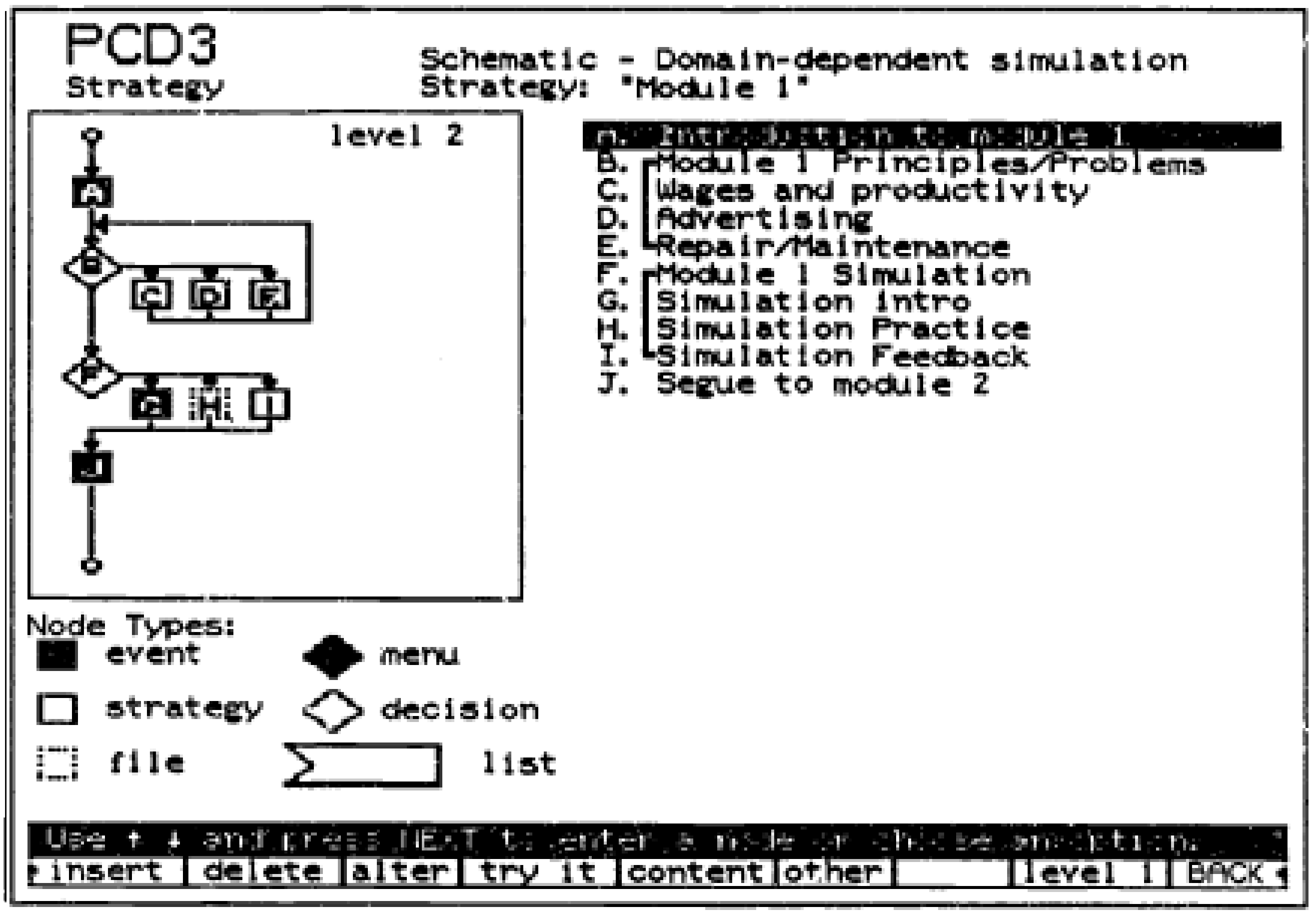

Figure 4. Structure of instructional unit 1.

Figure 5 shows a typical expository screen, including a worked example demonstrating the application of a principle.

Figure 6 shows a practice problem in which the student is able to employ a set of principles in an isolated context. Principles are like rules-of-thumb, and consequently there is generally not one correct application of a principle, but effective applications fall into ranges. The practice problems allow the student to identify these ranges, based on the feedback given, and select values within them to make good decisions. As principles are combined into more complex problem solutions, correct response ranges vary according to the interrelationships of the principles involved.

For instance, the effects of advertising in an isolated context are relatively easy to observe; more advertising leads to more demand. However, the selling price of the product also affects demand and the available production capacity may not be able to accommodate an increased demand. An understanding of the effects of advertising in relation to other principles is more important than a knowledge of the simple effects of advertising. As more of these principles are introduced into the context, problem solutions require an understanding of the principles and their effects, rather than learned values only.

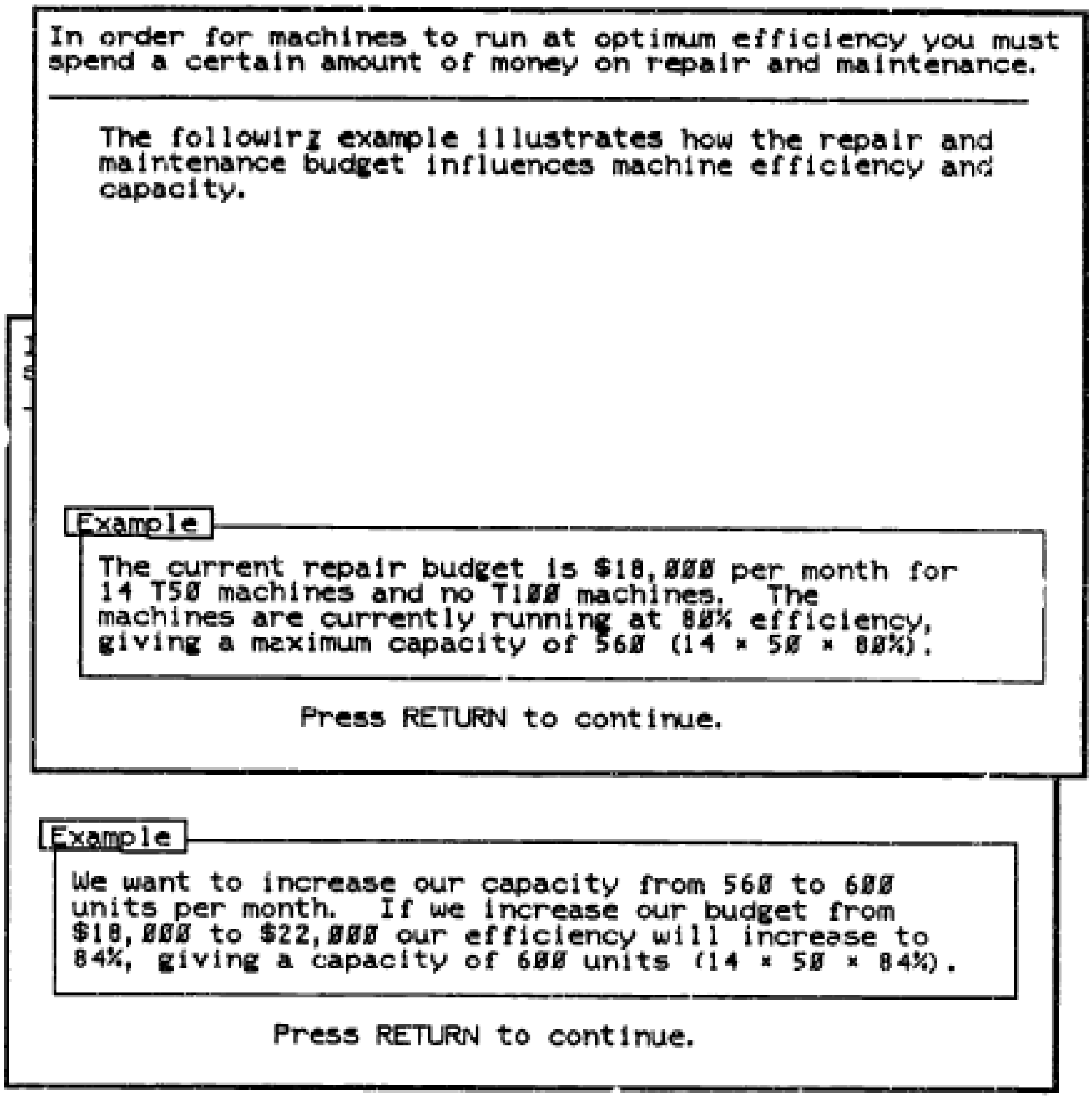

Figure 5. Expository screen with worked example for instructional unit 1.

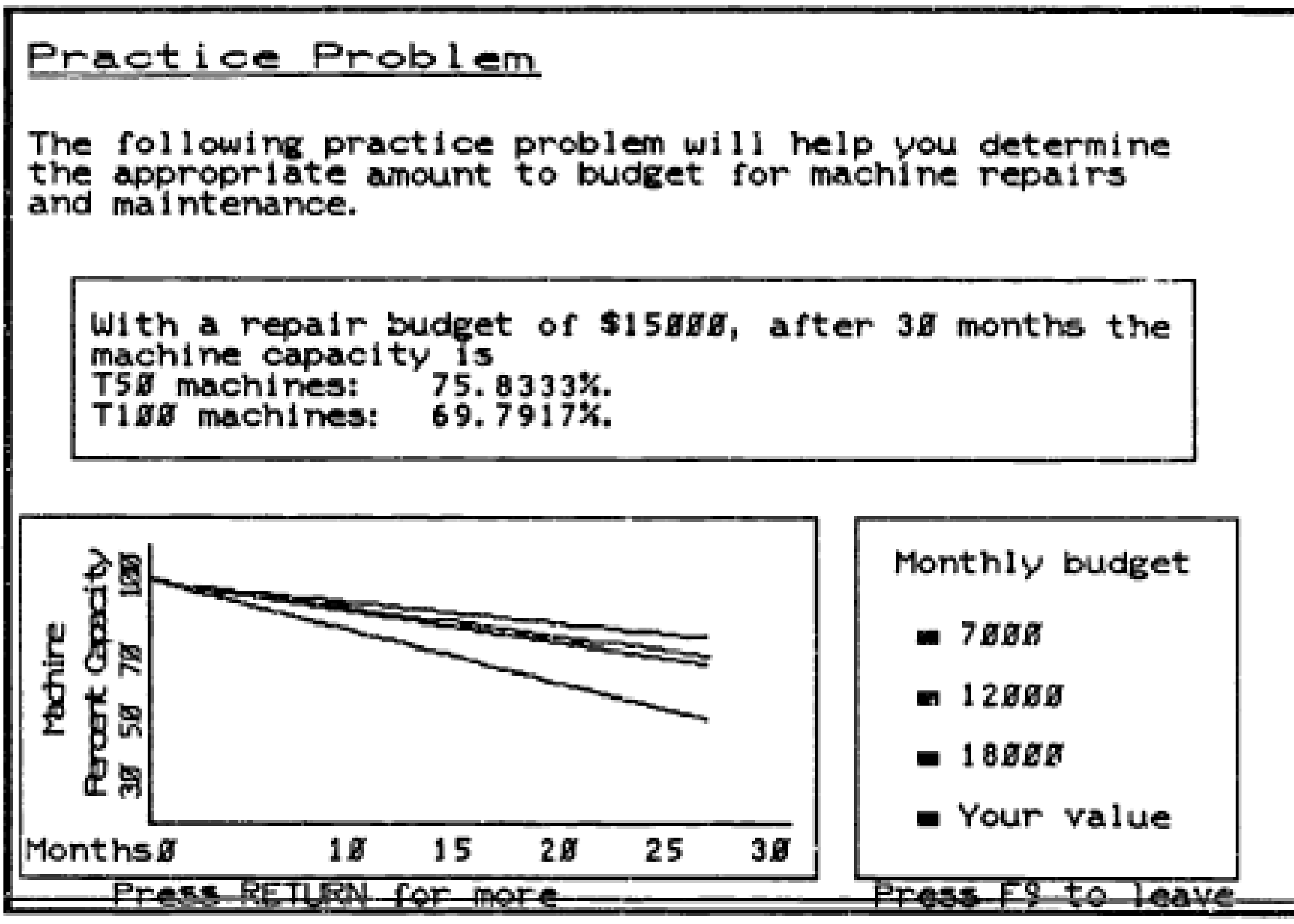

Figure 6. Practice problem for instructional unit 1.

At the end of each instructional unit the student is branched to the management simulation, but is only allowed to make decisions which require principles covered in that specific unit. All other variables and conditions of the simulation are held at constant levels. This allows the student to see the inter-relationships of the selected principles in the context of the simulation, but isolated from decisions related to other principles.

Figure 7 shows the choices given to the student in the simulation for unit 1. These choices correspond to the problems and related principles covered in this unit. The student is branched through three planning periods (months) and then returned to the instruction to begin unit two. At the end of each planning period, the student is given detailed information (see Figure 7) about the performance of the company during that period.

At the conclusion of the three instructional units (including the three unit simulations) the student is branched to the simulation again. At this point, the student is required to make all the decisions related to the management of the factory for twelve planning periods. Figure 8 shows the decisions the student makes in the complete simulation. Because of the increased complexity of the complete simulation, twelve cycles are necessary to allow students to encounter problems and follow through on solution strategies. Again, the student is given detailed information at the conclusion of each planning period (see Figure 8).

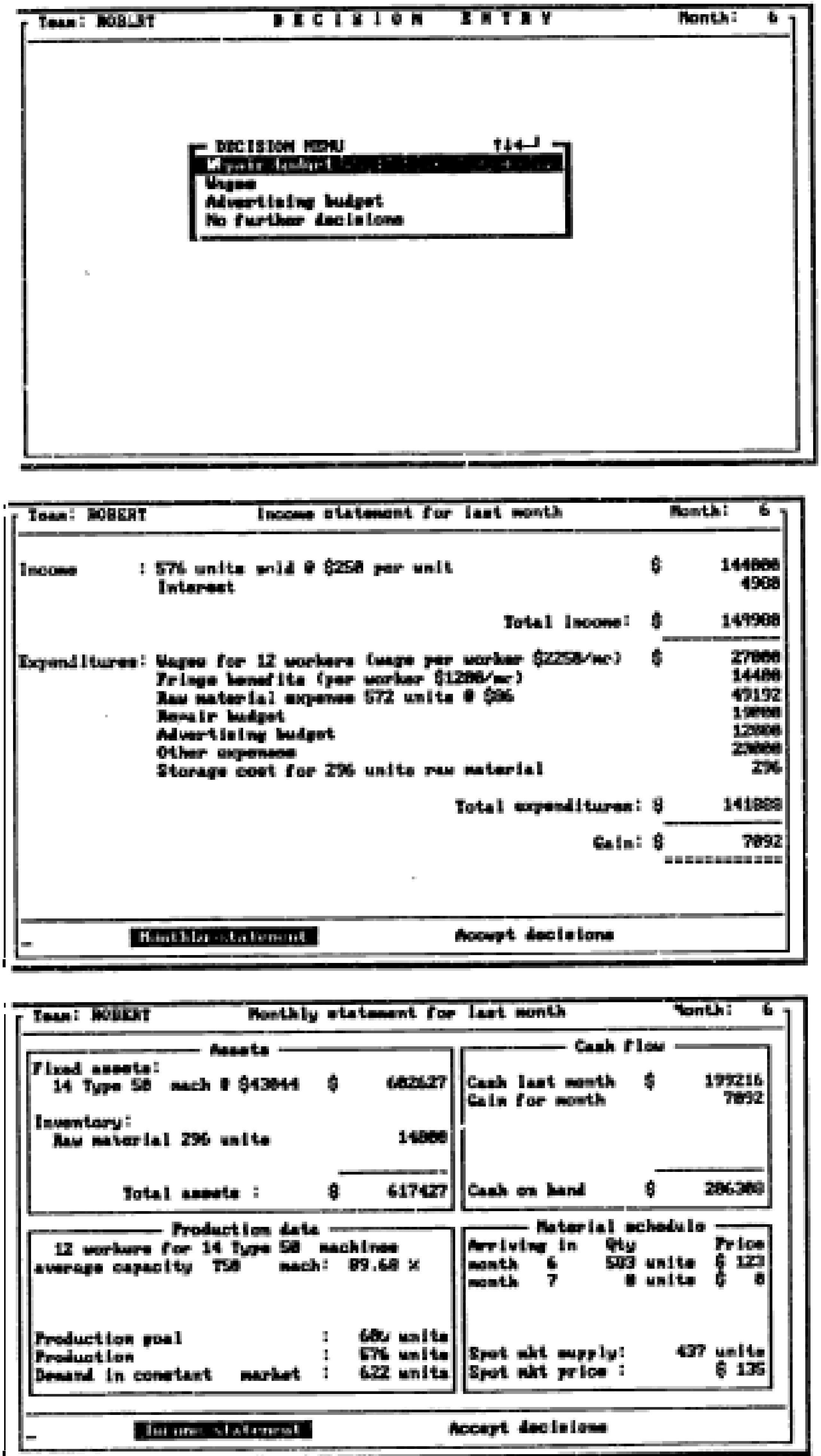

Figure 7. Module Simulation

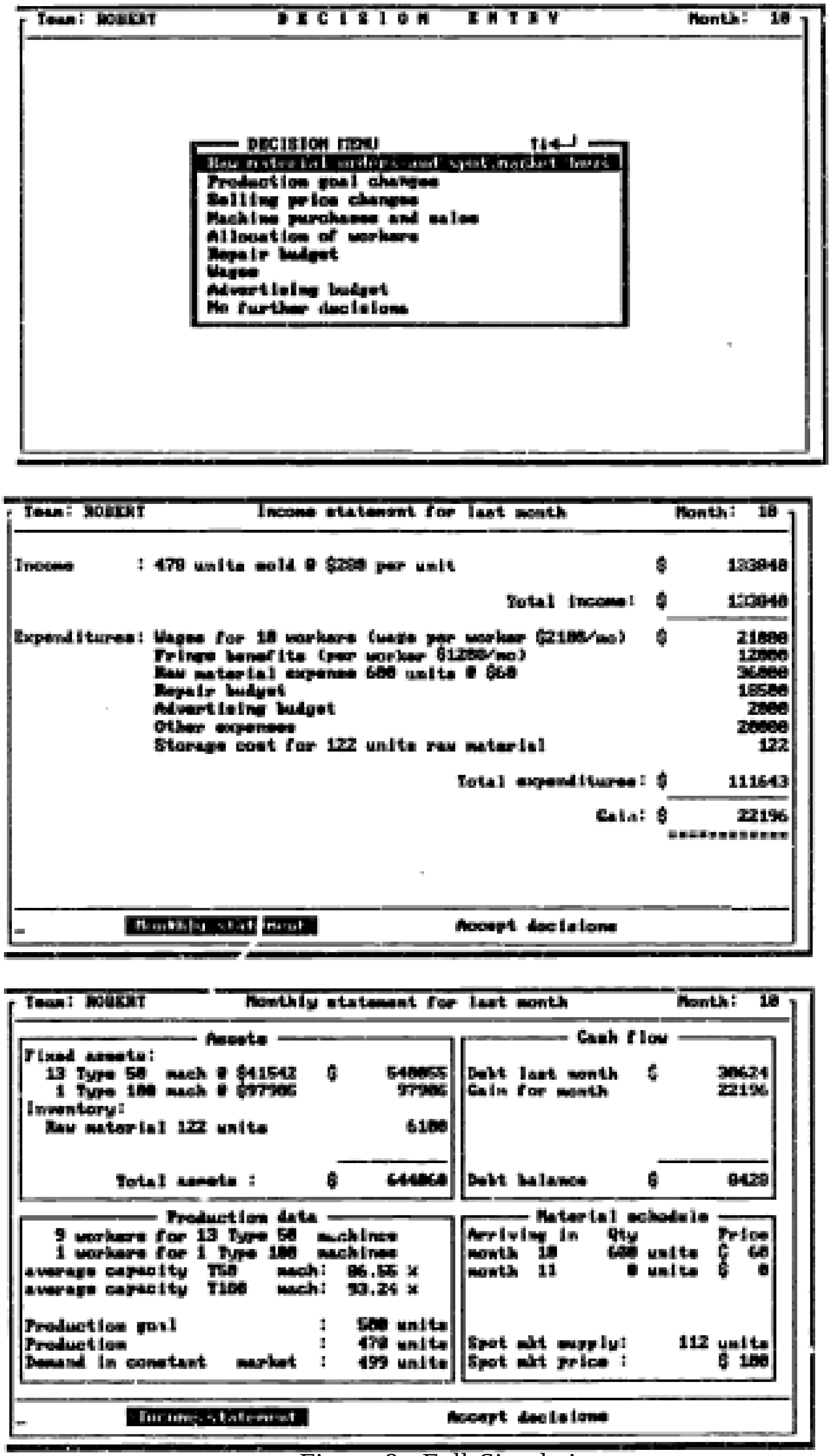

Figure 8. Full Simulation

Conclusion

The purpose of this paper was to discuss two related areas in which recent advancements in cognitive science and instructional technology may affect instructional design theory. The first area, information analysis, proposed extensions to current methods of content/task analysis procedures are made. Contextual module analysis proposes· an additional analysis of the information based upon complex-problems associated with a given situation. Whereas, conventional content and task analyses identify the attributes of the information, the contextual module analysis identifies the organization and accessibility of the information in reference to a given situation or culture (Wertsch, 1985). The modular· organization improves the service of the knowledge base for higher level employment situations (i.e., problem solving and creativity) (Rasch, 1988).

The second area proposed the framework for an ID model that directly links cognitive learning theory with specific instructional strategies. Rather than acquisition of knowledge in nonsense isolation, it is proposed that learners acquire knowledge within meaningful situations. Unfortunately, research in instructional design theory has focused on strategies associated with declarative and procedural knowledge with minimal empirical work for strategies associated with contextual knowledge (Tennyson & Christensen, 1988). Instructional technology should provide the means by which cognitive science can be applied to improvements in learning. That is, the behavioral paradigm was implemented by means of educational technology, we see the *same* thing happening for cognitive science.

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