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ABSTRACT

Scientific advancements in cognitive science and instructional technology extend the behaviorally-oriented learning paradigm of instructional design and management in three major areas: (1) analysis of information-to-be-learned; (2) means of evaluating learners; and (3) linkage of learning theory to instructional prescriptions. The two basic types of analysis of information-to-be-learned--content analysis and task analysis--both identify the external structure of the information without regard for how it might be stored in human memory. Cognitive science suggests that a context analysis should also be conducted and the concepts and their organization for employment identified to provide a means for sequencing instruction so that it improves the use of knowledge in problem solving. While learner evaluation in the behavioral paradigm focuses on observable student performance, evaluation in the cognitive paradigm takes on diagnostic functions. The implications for instructional design lie in the cognitive paradigm concepts of diagnosis of learning needs during instruction, and measures of achievement within the context of meaningful and complex situations. The instructional design model that is presented focuses on the planning of a learning environment which enables students not only to acquire knowledge, but also to improve their cognitive abilities to employ and extend their knowledge. Computer programs that are domain specific and provide for self-directed learning seem to offer excellent instructional strategies for meeting the goals of a curriculum that emphasizes higher-level thinking strategies. (11 references) (BBM)

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Instructional Design Theory: Advancements from Cognitive Science and Instructional Technology

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Instructional Design Theory:

Advancements from Cognitive Science and Instructional Technology

Scientific advancements in cognitive science and instructional technology suggest significant changes in methods of curricular and instructional design which will strongly affect educational practice. These advancements extend the predominately applied behaviorally-oriented learning paradigm of instructional design and management. In this article I will discuss three 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; (b) the means of evaluating learners; and, (c) 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 hierarchial 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 stored 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 on employment needs than by attribute or hierarchial associations. That is, the utility of the knowledge base is attributed to its 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. Better organization in memory may also imply better accessibility within the knowledge base for such higher order cognitive activities as problem solving and creativity.

To understand the nature of knowledge base organization, cognitive psychologist analysis problem complexity and the way individuals try to solve given problems. 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 is that the sequence of information for instruction should be based in part on internal associations as well as external structures. The assumption is that because external structures are independent of employment needs, an analysis of possible internal associations would improve the initial organization of the new information.

In addition to the analyzing of problems and solutions, is the issue of problem context. For example, expert systems reside within the constraints of a specific context: That is, they can solve problems only associated with that given context. 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). 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.

The change for content/task analysis suggested by cognitive science is the method of information analysis. In addition to the conventional content and task analyses, a context analysis is proposed if the goal of the instruction includes solving complex-problems. Basic steps for a context analysis are as follows:

-Define the context for the employment of the knowledge.

-Define the complex-problems associated with the context.

-Analysis solutions to identify concepts employed.

-Cluster the concepts according to employment.

-Organize the clusters into an associative network.

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.

Learner Evaluation

A second major area being affected by cognitive psychology is learner evaluation. In the behavioral paradigm, evaluation focuses only on observable student performance while, in contrast, evaluation in the cognitive paradigm takes on diagnostic functions. Evaluation is therefore more than checking attainment of behavioral objectives but, more importantly, a concurrent element of learning. For example, diagnosing learner needs during instruction has been a primary focus of empirical research that my colleagues and I have been working on for the past two decades. (A review of this program of research in adaptive instruction is found in Tennyson and Christensen [1988] and Tennyson and Park [1987]).

Much of the experimental programming efforts in intelligent computer-assisted instruction (ICAI) centers on techniques to identify mistakes and errors in solving problems (Dehn & Schank, 1982). Although not adaptive in preventing learning problems, ICAI programs are advancing the concept of finding possible problems and trying to help the student by prescribing specific instruction.

In the field of measurement, contemporary research is with design of instruments that measure inference making within meaningful contexts. The implication for instructional design is the construction of tests that evaluation problem solving within complex-context situations: Situations that go beyond the usual limited scope of measuring only right and wrong responses.

The implications for instructional design are in the cognitive paradigm concepts of (a) diagnosis of learning need during instruction and (b) measures of achievement within the context of meaningful and complex situations. That is, can the learner deal successfully with the type of problems requiring knowledge of when and why as well as knowing that and how.

Integrated Instructional Design Model

In this section I present a third area of cognitive psychology and instructional technology influences on ID theory: The development of an instructional design model that focuses on the planning of a learning environment so that students not only acquire knowledge but also improve their cognitive abilities to employ and extend their knowledge. In Figure 1, I present an instructional design model that shows the direct integration of cognitive learning theory with prescribed instructional strategies. In addition to the direct linkages between the various memory systems and instructional strategies, I propose that 70% of formal, classroom learning time use instructional prescriptions that focus on employing and improving knowledge. The major components of the ID model are: memory systems, learning objectives, instructional time, and instructional prescriptions. These are now discussed in turn.

Insert Figure 1 about here

Memory systems. The proposed ID model is directly associated to the cognitive paradigm of learning. A complete discussion of this paradigm is fould in Tennyson and Rasch (1988). Because the goals of the ID model include both the acquisition and the employment of knowledge, the memory systems reference the long-term memory subsystems of storage and retrieval. 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; and, contextual knowledge, knowing "when and why" to use given information. The retrieval system is composed of cognitive abilities associated with the processes of recall, problem solving, and creativity.

Proposed in the ID model (see Figure 1) is that there is a connection between the five basic memory systems and prescribed instructional strategies. The purpose for including this component in the ID model is twofold: First, to establish a direct link 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. Thus, I have attempted in this article 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 the educational goals of knowledge acquisition and employment. The focus of the cognitive paradigm is on both of these educational goals as contrasted to the behavioral paradigm which only concerns itself with the acquisition goal. Within the proposed ID model, the learning objectives extend the macro level goals so as to tie directly with the memory systems component.

Learning objectives. The purpose of cognitive-based learning objectives is to further elaborate the curricular goals of knowledge acquisition and employment. Objectives are important in the planning of learning environments because they provide the means of both allocating instructional time and identifying specific instructional strategies. I 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 schematic 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. Contextual knowledge includes the criteria, values, and appropriateness of a given domains schematic 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.

-<u>Cognitive strategies</u>. This objective deals with both the development of cognitive complexity abilities and the improvement of domain specific strategies of thinking. Thus, this category of learning objectives deals with two important issues in education. First, the elaboration of thinking strategies that will arm the students with increased domain specific contextual knowledge. Second, the development of the cognitive abilities of differentiation and integration. These abilities provide the cognitive tools to effectively employ and improve the knowledge base; therefore, they are integral to any educational goal seeking to improve thinking strategies.

-<u>Creative Processes</u>. This objective deals with the most elusive goal of education: the development and improvement of learner creative abilities. I define creativity as a two fold ability: First, creating knowledge to solve a problem from the external environment; and, second, creating the problem as well as the knowledge. Integral to the creating of both the problem and knowledge is the criteria by which consistent judgement can be made. I define two forms of criteria as follows: The first is criteria that are known and which can be applied with a high level of consistency. In contrast are criteria that are developed concurrently with the problem and/or knowledge, and is consistently applied across a high level of productivity. Creativity objectives need to specify not only the ability to develope and improve, but also the form of criteria. That is, students should be informed of the criteria in the former and, in the latter, the necessity to develop criteria.

Instructional time. A key factor in implementing the cognitive goals of knowledge acquisition and employment is the allocation of learning time by defined objectives. For example, Tennyson and Rasch (1988) suggest that if improvements in problem solving and creativity are to occur, there needs to be a significant change in how instructional time is allocated. They recommend that the conventional instructional time allocation for learning be altered so that, instead of 70% of instruction aimed at the declarative and procedural knowledge levels of learning, 70% be devoted to learning and thinking situations that involve acquisition of contextual knowledge and development of cognitive abilities.

Using Tennyson and Rasch's recommended figures on instructional time allocation, I propose that learning time be divided between the two main subsystems of long-time memory--storage and retrieval. Within the guidelines illustrated in Figure 1, time is assigned according to the cognitive objectives defined in the previous section. In the storage system, learning time is allocated among the three memory systems making up a knowledge base as follows: declarative knowledge 10%; procedure knowledge 20%; and contextual knowledge 25%. I am recommending that contextual knowledge learning time be about equal to the other two knowledge forms because of the necessity to both organize a knowledge base and develop accessibility. The value of a knowledge base is primarily in the functionality of its organization and accessibility . Without a sufficient base of contextual knowledge, the opportunity for employment, future elaborations, and extension of the knowledge base is severely limited.

For the knowledge acquisition goal, the focus of learning time allocation is on contextual knowledge, and away from the usual practice of heavy emphasis on amount of information. I am assuming that declarative and procedural knowledge acquisition is an interactive process that is improved when employing the knowledge base in the service of higher-order thinking situations (i.e., problem solving and creativity). Time allocated for declarative and procedural knowledge focuses on establishing an initial base of necessary knowledge that can be used within a context of a problem situation. That is, learning time should include the opportunity for the learner to gain experience in employing the knowledge.

The learning times presented in Figure 1 do not imply a linear sequence of knowledge acquisition going from declarative to contextual. Rather, they represent total amounts in an iterative learning environment where learners are continuously acquiring each form of knowledge. For example, students may engage in contextual knowledge acquisition prior to declarative knowledge acquisition if they currently have sufficient background knowledge (i.e., a discovery method of instruction as contrasted to a structured method).

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

The five 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 1). 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. 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 schemas.

Following the contextual introduction of the information, additional expository instructional variables present the ideas, concepts, principles, rules, facts, etc. 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 labelled practice, because the objective is to learn how to use knowledge correctly; therefore, it requires constant interaction between student learning (e.g., problem solving) and instructional system monitoring. Practice strategies should attempt to create an environment in which (a) the student learns to apply knowledge to previously unencountered 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. In the proposed ID model (Figure 1), I propose that 25% of the instructional time be allocated to the acquisition of contextual knowledge. A proposed instructional strategy for this category uses problem-oriented simulation techniques. The purpose of simulations 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.

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 among the facts, concepts, rules, and principles of specific domains of information.

<u>Complex-dynamic strategies</u>. Employment of the knowledge base in the service of recall, problem solving and creativity is the second major educational goal of learning environments. In contrast to instructional systems that use domain-independent thinking skills development, this instructional strategy category proposes the presentation of domain-specific situations that allow learners to develop their thinking processes while employing the domain knowledge stored in their own memory systems. As such, complex-dynamic simulations extend the format of the problem-oriented

simulations by use of an iterative format that not only shows the consequences of decisions but also updates the situational conditions and proceeds to make the next iteration more complex. That is, the situation is longitudinal, allowing for increasing difficulty as well as providing additions, deletions, and changes in variables and conditions. In sophisticated complex-dynamic simulations these alterations and changes are done according to individual differences (Breuer, 1987).

The main features of complex-dynamic simulations are: (a) present the initial variables and conditions of the situation; (b) assess the learner's proposed solution; and (c) establish the next iteration of the variables and conditions based on the cumulative efforts of the learner (Breuer & Kummer, in press).

In summary, complex-dynamic strategies should be designed to provide a learning environment in which learners develop and improve higher-order thinking processes by engaging in situations that require the employment of their knowledge base in the service of problem solving.

Self-directed experiences. The creative process is a cognitive ability that seemingly can be improved by learners who engage in activities requiring novel and valuable outcomes. That is, the creative process can be improved by instructional methods that allow students the opportunity to create knowledge within the context of a given domain. Instructional programs that provide an environment for easy manipulation of new information increase the learning time available for such activities.

Computer-based software programs provide environments for self-directed learning experiences that may improve the creative process within given domains. For example, word processing programs have been shown to improve writing skills because of the ease in correcting and adjusting text structure (Lawler, 1985; Zvacek, 1988). Computer-based simulations have also shown that the creative process can be improved when students can both continually see the outcomes of their decisions while understanding the predictability of their decisions (Rasch, 1988).

The creative process is a cognitive ability that apparently can be improved with use within a domain and computer-based software programs seem to provide the type of environment which can enhance instructional methods for such improvements. Because of the time necessary for participating in creative activities, educators should provide sufficient learning time for such development (Tennyson, 1988). Computer software programs that are domain specific enhance the cost-effectiveness of instructional strategies aimed at the improvement of creativity.

The key instructional attribute for this category is an environment that allows students to experience the creative process at that given moment. Computer software programs that are domain specific and provide for self-directed learning seem to offer excellent instructional strategies for meeting goals of a curriculum that emphasizes higher-level thinking strategies. Although, we have focused on computer-based software in this instructional category, there are of course other possible instructional means for students improving their creative processes.

Conclusion

The purpose of this article was to discuss several areas in which recent advancements in cognitive psychology and educational technology may affect instructional design theory. The first two areas, information analysis and learner evaluation, proposed extensions to current methods of instructional development. Information analysis proposes an additional analysis of the information based upon complex-problems associated with a given context. Whereas, a conventional content/task analysis identify the attributes of the information, the context analysis identifies the schematic organization of the information. The schematic organization improves the service of the knowledge base for higher level employment situations (i.e., problem solving and creativity).

The effect of cognitive psychology on learner evaluation deals with two fundamental aspects of evaluation. First, when do it and, second, what to measure. For the former aspect of when, it is proposed that evaluation be of a diagnostic nature, occurring during learning. Diagnosing learning need while learning would improve the instructional prescription. That is, the instructional program would be adjusting to current individual needs and differences. For the latter aspect, the focus of evaluation would be on higher order inference making both within specific domains and cognitive abilities.

The third area proposed the framework for an ID model that directly links cognitive learning theory with specific instructional strategies. I also proposed that learning time be allocated according to the educational goals of knowledge acquisition and employment. Given the assumption that learners can elaborate and extend their knowledge base during employment, instructional time was shifted from the traditional allocation of 70% for acquisition to 70% for improvements in employment. This reallocation of instructional time does not reduce the importance of content, but places more of the burden of acquisition on the learner. Rather than acquisition of knowledge in nonsense isolation, it is proposed that learners acquire knowledge within meaningful situations. Unfortunately, research in instructional theory has focused on strategies associated with declarative and procedural knowledge with minimal empirical work for strategies associated with contextual knowledge and cognitive abilities. Educational technology should provide the means by which cognitive psychology can be applied to improvements in learning. That is, the behavioral paradigm was implemented by means of educational technology, I see the same thing happening for cognitive psychology.

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Figure Captions

Figure 1. Instructional design model linking cognitive learning theory with instructional prescriptions.

	Educational Goals				
ID Model					
Components	Acquisition of Knowledge			Employment of Knowledge	
Memory Systems	Declarative Knowledge	Procedural Knowledge	Contextual Knowledge	Cognitive Complexity	Total Cognitive System
Learning Objectives	Verbal Information	Intellectual Skills	Contextual Skills	Cognitive Strategies	Creative Processes
Instructional Times	10%	20%	25%	30%	15%
Instructional Prescriptions	Expository Strategies	Practice Strategies	Problem-Oriented Strategies	Complex-Dynamic Strategies	Self-Directed Experiences