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ABSTRACT

This paper examines the cognitive processes associated with higher-order thinking strategies--i.e., cognitive processes directly associated with the employment of knowledge in the service of problem solving and creativity--in order to more clearly define a prescribed instructional method to improve problem-solving skills. The first section of the paper presents an overview of a learning and cognition model for the purposes of illustrating the relationship between the proposed instructional method and higher-order thinking strategies, and discusses a number of specific basic components of the cognitive system model, e.g., perception, short-term and working memory, and long-term memory. In addition, the following related concepts are explored: (1) cognitive complexity; (2) criteria; (3) intelligence; (4) conditions in the development of thinking strategies; (5) recall; (6) problem-solving; and (7) creativity. The second part of the paper establishes an interest in complex problem simulations that can help students improve their cognitive complexity in problem solving. As an example of this, it is noted that the Minnesota Adaptive Instructional System (MAIS) offers a system that integrates higher-order thinking strategies and knowledge acquisition. Also described here is the design strategy of complex problem simulations, the components of which include necessary knowledge, simulation, and learning environment. The third section briefly describes some software examples of this instructional method. (30 references) (CGD)

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Cognitive Science and Instructional Technology: Improvements in Higher Order Thinking Strategies

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Cognitive Science and Instructional Technology:
Improvements in Higher-Order Thinking Strategies

A recent national report on education concluded that society's future depends on a citizenry that can "think and reason creatively and deliberately; develop sound judgments of information (and) understand and contend effectively with rapid and constant change..." (National Commission, 1983). Likewise, a national teacher education task force urged the development of a curriculum "that emphasizes higher-order thinking strategies" (National Task Force, 1986). In other words, the purpose of education should include not only the acquisition of knowledge, but also the development and improvement of higher-order cognitive processes. Unfortunately, the achievement of these learning goals still elude educators even after decades of concern because of the serious lack of basic research on instructional strategies that can empirically demonstrate the improved learning of higher-order thinking strategies.

However, in the last decade developments in cognitive science have forged interdisciplinary approaches to learning and thinking such that we now seem to understand more about how and why people both acquire knowledge and employ it in the service of problem solving (Gagne & Glaser, 1987). These advancements, in what can be called cognitive learning theories (Tennyson & Christensen, 1988), offer a means to not only more fully understand learning and thinking processes but they also provide the means necessary for prescribing instructional strategies that can predictably improve these cognitive processes (Wertheimer, 1985).

Higher-order thinking involves cognitive processes directly associated with the employment of knowledge in the service of problem solving and creativity (Gagne, 1985). Basically, these processes enable the individual to "restructure" their knowledge by (a) analyzing a given situation, (b) working out a conceptualization of the situation, (c) defining specific goals for coping with the situation, and (d) establishing a possible solution (Breuer & Hajovy, 1987).

Complex problem simulations. The purpose of this paper is to present an instructional method that has been empirically shown to significantly improve higher-order thinking strategies (i.e., problem solving). The method employs computer-managed simulations that present contextually meaningful problem situations that require students to prepare solution proposals. The simulation assesses the proposal and offers the students the consequences of their decisions while also iteratively updating the situational conditions. This type of simulation, unlike conventional simulations which are used for the acquisition of knowledge, presents dynamic problems, requiring the students to fully employ their knowledge base by generating solutions to domain-specific problems (Bransford & Stein, 1984).

In this paper I will first elaborate on the cognitive processes associated with higher-order thinking strategies so as to more clearly define the prescribed instructional method to improve problem solving. Following that presentation, I will describe the instructional strategy and, finally, present software examples of the method.

Learning and Cognition

An important contribution of cognitive psychology in the past decade has been the development of theories and models to explain the processes of learning and cognition (Streufert, Streufert, & Denson, 1985). The value of these theories is that they offer operational definitions of not only how learning occurs but why it occurs. The why explanation provides more direct means for understanding how instructional strategies may accomplish predictable improvements in both learning and thinking.

Cognitive Model

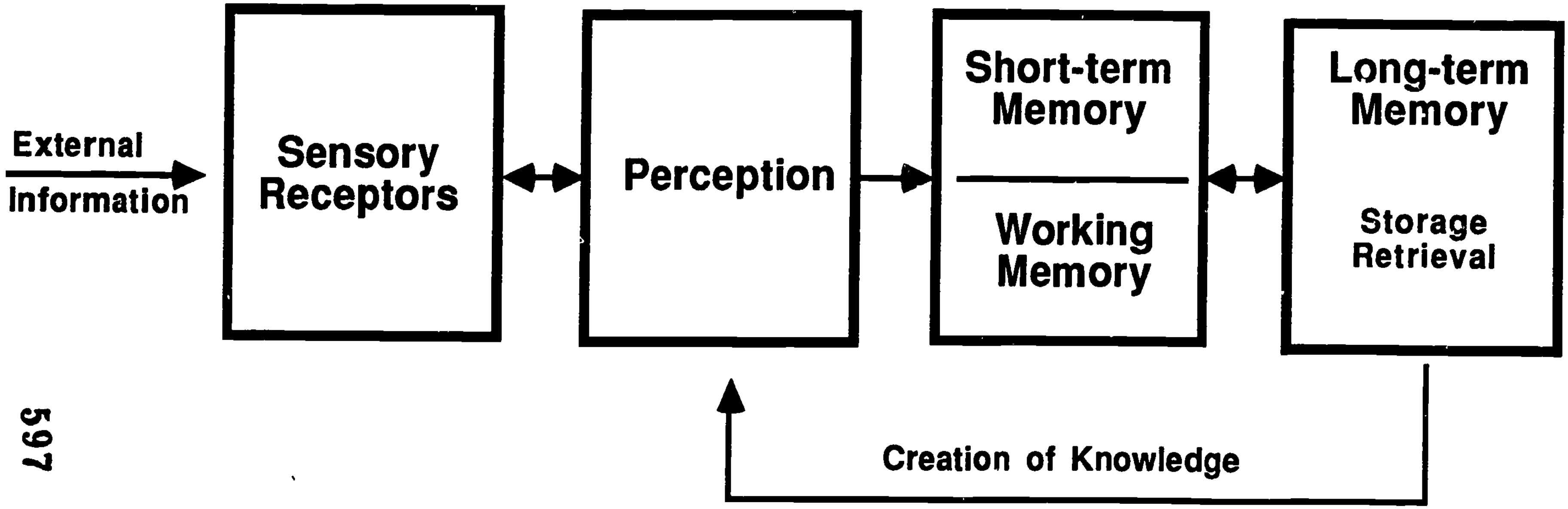
In this section I present an overview of a learning and cognition model to illustrate the relationship between the proposed instructional method and higher-order thinking strategies (Tennyson & Christensen, 1988). Figure 1 shows that the acquisition of knowledge comes from both external and internal sources. This is an important concept to the instructional issue of developing and improving higher-order thinking strategies because most cognitive theories assume these processes to be controlled by internal cognitive systems. That is, to operationally account for them, it is necessary to consider instructional strategies that include direct reference to internal cognitive systems as well as ones that always rely on learning as occurring from external sources only (Anderson, 1980, 1982). The basic components of our cognitive system model include the following: sensory receptors (i.e., eyes, ears, touch, etc.), perception, short-term and working-memory, and long-term memory (storage and retrieval).

Insert Figure 1 about here

Perception. Information coming from either external or internal sources passes through the perception component which performs the function of being aware of and assessing the potential value of the information for purposes of attention and effort in cognitive processing (Doerner, 1983).

Short-term and working memory. The next component consists of two forms of memory that only deal with immediate cognitive processes: short-term memory and working memory. Short-term memory is defined as having a limited capacity in which information is maintained only for the moment at hand (actually only a few seconds at maximum). Working memory on the other hand involves conscious effort or metacognitive awareness of the encoding process between itself and long-term memory (Brown, Armbruster, & Baker, 1984).

Long-term memory. The acquisition of information (learning) and the means to employ it (thinking) occurs within the storage and retrieval subsystems of the long-term memory component. The storage system is where new



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Cognitive System

information is learned and assimilated into the existing knowledge base. A knowledge base can be described as an associative network of concepts (or schemas) varying per individual according to amount, organization, and accessibility of its information (Rabinowitz & Glaser, 1985).

The retrieval system involves the twofold cognitive process of selecting and organizing knowledge for purposes associated with a given situation. That is, the former process differentiates knowledge in memory based upon criteria for selection, while the latter process integrates the knowledge for serving the given need (Schroder & Suedfeld, 1971). It is in the retrieval system that we are most concerned with when considering instructional strategies to improve higher-order thinking processes. In Figure 2, we illustrate the distinctions between the two sub-systems of long-term memory.

Insert Figure 2 about here

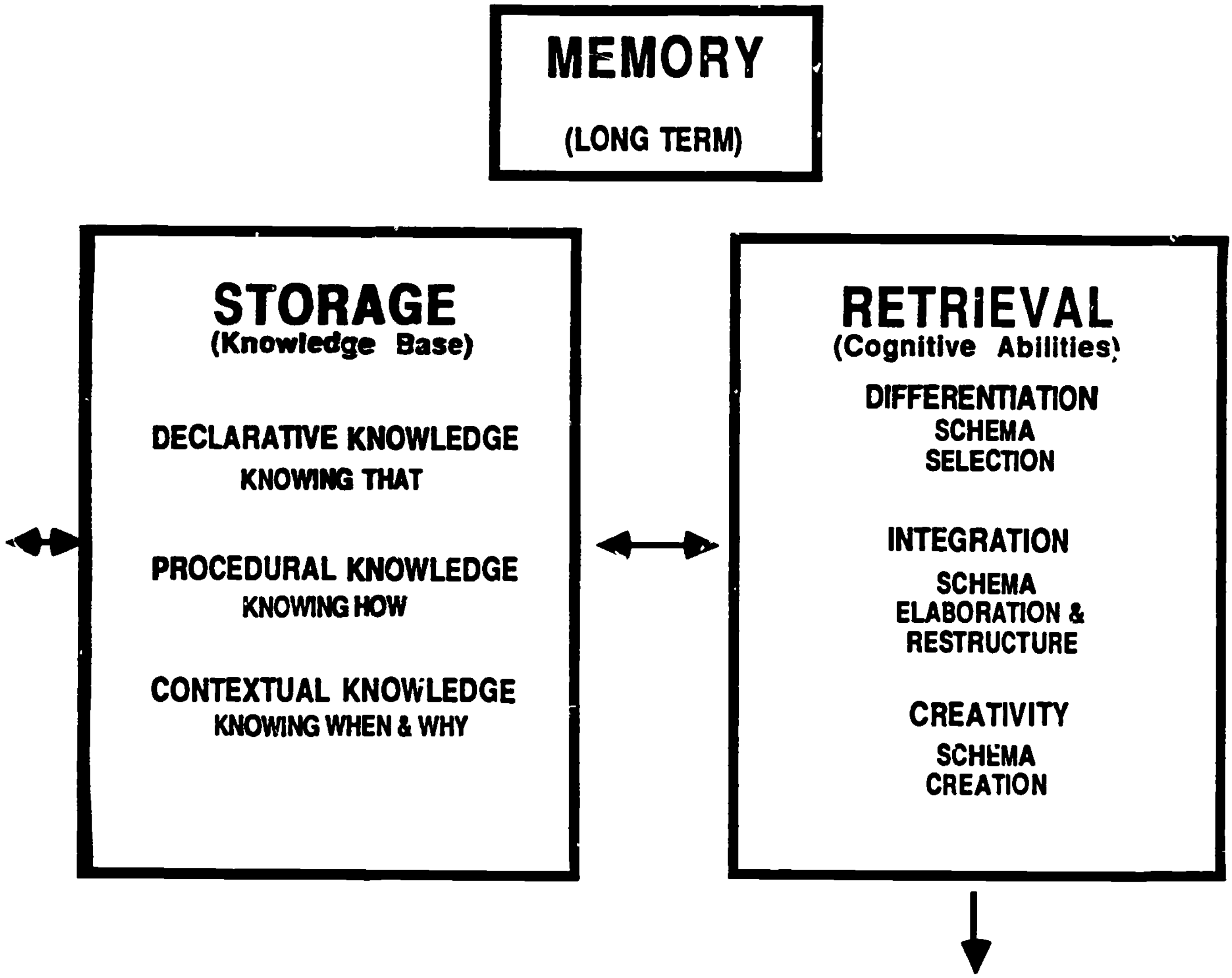
Within the storage system of memory there are various forms of knowledge: declarative, procedural, and contextual (Shiffrin & Dumais, 1981). Each form represents a different memory system or function. Declarative knowledge implies an understanding and awareness of information and refers to the "knowing that," for example, that underlining keywords in a text will help recall. Procedural knowledge implies a "knowing how" to employ concepts, rules, and principles in the service of given situations. Contextual knowledge implies an understanding of when and why to select specific concepts, rules, principles from the knowledge base. The selection process is governed by criteria (e.g., values and situational appropriateness). Whereas both declarative and procedural knowledge form the amount of information in a knowledge base, contextual knowledge forms its organization and accessibility.

The retrieval system of memory employs the knowledge base for the thinking strategies associated with recall, problem solving, and creativity (see Figure 2). Recall simply implies the automatic selecting of knowledge directly as stored in memory. Problem solving involves more complex thinking strategies that require both the cognitive processes of differentiation and integration (restructing) of information from the knowledge base. Creativity is the highest order of thinking because it implies the creating of knowledge as well as the employment of the cognitive processes of differentiation and integration.

<u>Cognitive Complexity</u>

Higher-order thinking involves three cognitive processes: differentiation, integration, and creation of knowledge. The first two processes occur primarily in the retrieval system of memory while the third further involves the other components of the entire cognitive system (see Figure 1).

The operational term for the retrieval system functions of differentiation and integration is <u>cognitive complexity</u> (Schroder, 1971). Cognitive


MEMORY
(LONG TERM)
STORAGE
(Knowledge Base)
DECLARATIVE KNOWLEDGE
KNOWING THAT
PROCEDURAL KNOWLEDGE
KNOWING HOW
CONTEXTUAL KNOWLEDGE
KNOWING WHEN & WHY
RETRIEVAL
(Cognitive Abilities)
DIFFERENTIATION
SCHEMA
SELECTION
INTEGRATION
SCHEMA
ELABORATION &
RESTRUCTURE
CREATIVITY
SCHEMA
CREATION

complexity, as contrasted to intelligence (which seems to be more of a trait cognitive condition), is an ability that can be developed and improved with direct instructional intervention. Differentiation is defined as a twofold cognitive process as follows: (a) the ability to understand a given situation; and (b) the ability to apply appropriate criteria by which to select necessary knowledge from storage. Integration is the process of forming new schema(s) from selected knowledge. Creativity is the process to form new knowledge by employing the total cognitive system.

Criteria. An important aspect of the differentiation process is the concept of criteria. Criteria are the standards or values by which a judgment or decision of selection may be based. Criteria are an integral attribute of contextual knowledge (Paris, Cross, & Lipson, 1984). However, in higher-order thinking situations, criteria may have to be developed within the context of the integration and creation processes. Because many higher-order thinking situations do not necessarily exhibit right or wrong criteria for knowledge differentiation, values in terms of functional or moral reasoning need to be an integral part of such problem solving and creative situations.

Within the context of contemporary research in cognitive complexity, Kohlberg's (1981) theory of moral reasoning has been used to explain situational decision making (Streufert & Swezey, 1986). Kohlberg considers moral reasoning as an ability that can be developed and, as Hunt (1975) points out, should be learned concurrently with the acquisition of contextual knowledge. For my purposes here, we need to consider only Kohlberg's conventional and postconventional levels. Basically, the conventional level involves values associated with the general society, either in terms of culture and customs or laws and rules. The postconventional level focuses on individuals developing their own values in terms of ethical principles they choose to follow (Note. Stage 5, are standards usually agreed upon by society, while Stage 6, are self-chosen standards).

Intelligence

I have defined cognitive complexity as an ability that can be improved and, as such, is not necessarily correlated to intelligence (Simon, 1980). However, in a schooling environment, intelligence needs to be considered along with cognitive complexity so as to insure that the students are developing their full potential in all possible areas of knowledge (Flavell, 1977). That is, the more fully developed the knowledge base in memory, the greater the opportunities for differentiation and integration, and, possibly, creation of knowledge. Although the debate on theories of intelligence is beyond the scope of this article, I take a pragmatic view that there are a number of definable kinds of intelligence.

The contemporary work of Gardner (1984) updates the notion of multiple intelligences by identifying seven largely autonomous kinds of human intelligences. Each tends to have its own original location in the brain, each arises on its own schedule in the normal development of the brain and each functions uniquely. Gardner's seven intelligences are linguistic, musical, logical-mathematical, spatial, bodily-kinesthetic, perception of self, and sense of others. The first four form the intelligences which are most associated with cognitive processing, but the latter two are important for development of criterial values integral to differentiation.

The cognitive processes of differentiation, integration, and creation of knowledge are abilities that can be improved by effective instructional strategies. Intelligence, on the other hand, seems not to be directly influenced by instructional conditions: however, in curriculum planning, education should be concerned with the enhancement of all kinds of intelligences while prescribing instruction that improves both the acquisition of knowledge and the development of thinking strategies in problem solving and creativity.

Next I summarize how the cognitive complexity processes of differentiation and integration form conditions for thinking strategies. Within this summary, I will indicate how criteria and intelligence interact with the various conditions.

Conditions in the Development of Thinking Strategies

Thinking strategies represent a continuum of conditions ranging from a low-order of automatic recall of existing knowledge to a high-order of creative thought (see Figure 2). In Table 1, I summarize the three conditions associated with thinking strategies (i.e., recall, problem solving, and creativity) by their respective employment of the cognitive processes of differentiation, integration, and creation of knowledge. The conditions are further categorized by identifying situational characteristics and their respective criteria.

Insert Table 1 about here

Recall. The first thinking strategy, recall, represents the retrieval of knowledge from memory as it exists. This first condition is the most basic and automatic form of knowledge employment for the purpose of serving previously encountered situations. Situations represent problems that were either learned concurrently with the information or gained later through experience.

Recall strategies involve an automatic differentiation of knowlege from the existing knowledge base. The criteria for differentiation is an integral part of the contextual knowledge. For example, when a musician is asked to perform a familiar piece of music, the existing schema is retrieved from long-term memory and executed without modification. The cognitive process involved is the differentiation of the appropriate schema from others organized in the knowledge base.

A higher-order recall strategy is employed when more complex situations in which new conditions that have not been previously encountered are part of the

Table 1

Thinking Strategies: Recall, Problem Solving, and Creativity

Situation	Conditions	Criteria
	Recall	
Previously encountered	Differentiate from existing schemata	Part of schemata
Previously encountered/ new conditions	Differentiate and integrate from existing schemata	Part of schemata
	Problem Solving	
Previously unencountered	Differentiate and integrate to form new schema	Part of schemata
Previously unencountered	Create knowledge, differentiate, and integrate to form new schema	Develop new criteria
	Creativity	
Create	Differentiate and integrate to form new schema	Part of schemata
Create	Create knowledge, differentiate, and integrate to form new schema	Develop new criteria

problem. This cognitive process is still automatic for differentiation but given the new conditions, integration of knowledge from existing schemata must be done. This is the condition of cognitive processing that most experts operate at because of the sophistication of their knowledge base gained from experiences. Again, the criteria for differentiation is part of the existing contextual knowledge.

For example, when a musician is asked to perform a familiar piece of music under altered conditions (e.g., in a new key or a new arrangement) differentiation is not the only cognitive process needed. While the schema for the music is retrieved, the musician must also retrieve existing schema that deal with the new conditions (e.g., how to transpose from one key to another). The integration of all appropriate schemata is required to succeed at the task.

Problem solving. This condition is primarily associated with situations dealing with previously unencountered problems. That is, the term problem solving is most often defined for situations that require employing knowledge in the service of problems not already in storage. In these types of situations, the thinking strategies require the integration of knowledge to form new schema.

A first condition of problem solving involves the differentiation process of selecting knowledge that is currently in storage using known criteria. Concurrently, the selected knowledge is integrated to form a new schema. Cognitive complexity within this condition focuses on elaborating the existing knowledge base. For example, when learning an entirely new piece of music, a musician must create a new schema for the music in the retrieval system of long-term memory. This is accomplished by differentiating the known elements of all music that exist in the piece, and integrating them with new connections into a representation of the unfamiliar music. The new schema then becomes part of the knowledge base.

In contrast to the above problem situation, are those in which the current knowledge base is insufficient, requiring therefore the creation of knowledge by employing the entire cognitive system (see Figure 1). That is, given that the necessary knowledge to solve the problem is not in memory, new knowledge must be created by: (a) the internal processes of extending, elaborating, transferring, and forming new linkages; (b) the external process of acquiring information; or (c) a combination of the two. Concurrently, new criteria for the differentiation process must be developed. Obviously, with this condition, Kohlberg's first postconventional level would be most preferred for criteria development because of the concern for values with a social contract orientation. It is also at this stage that the Gardner's kinds of intelligences become important factors in solving the problem. Thus, the sophistication of a proposed solution is a factor of the person's knowledge base, level of cognitive complexity, higher-order thinking strategies, and intelligence.

For example, if a highly trained classical musician is ask · perform jazz, it may require the creation of new knowledge about jazz id s. This new knowledge may be developed either by the internal three-way interaction of the musician's cognitive complexity, higher-order thinking strategies, and musical intelligence or by combining the three with external information sources (e.g., an expert in jazz). It will also require the development of new criteria for determining the quality of the performance based on criteria held by the jazz community.

Creativity. The highest order of human cognitive processing is the creating of the problem situation. Rather than having the external environment dictate the situation, the individual, internally, creates the need or problem.

Within one condition, the individual creates new situations but only within his/her own current knowledge base. Differentiation is done within the schemata and criteria available. Solution to the situation is done by integration of the selected knowledge in forming a new schema.

For example, composers often have a recognizable style in their music even though individual pieces are new and varied. That is, utilizing the existing knowledge base they create new music judging its quality against existing criteria.

The highest cognitive condition exists when the individual creates not only the situation, but also the new knowledge and criteria necessary for solution. Creating knowledge involves the entire cognitive system. Thus, in contrast to recall thinking strategies , which are characterized as the automatic functioning of the cognitive processes, creativity seems to involve both the conscientious deliberations of differentiation and integration and the spontaneous integrations that operate at a meta-cognition level of awareness.

For example, by developing or acquiring new compositional techniques, a composer may make an innovative change in style. That change may further require the development of new criteria corresponding to the new style. Differentiation and integration using the new criteria allows for the creation of new knowledge.

In the next section Iwill present an instructional strategy that has been empirically tested to develop and improve higher-order thinking processes (especially the cognitive processes of differentiation and integration). This work has been done within a program of research associated with the Minnesota Adaptive Instructional System (MAIS; Tennyson & Park, 1987).

Complex Problem Simulations

Simulation in educational computing is a widely employed technique to teach certain types of complex tasks (Breuer & Hajovy, 1987). The purpose for using simulations is to teach a task as a complete whole instead of in successive parts. For example, simulations are used in aviation training to replicate the complex interaction of a number of variables needed to successfully pilot an airplane. Learning the numerous variables simultaneously is necessary to fully understand the whole concept of flying. I define these types of simulations as problem-oriented because the educational objective is to learn the variables (i.e., declarative and procedural knowledge) and their context (i.e., contextual knowledge).

However, my concern in this paper is not with the acquisition of knowledge but the employment of knowledge in the service of problem solving. Thus, I am most concerned with simulations that will help students improve their cognitive complexity in problem solving; that is, cognitive processes associated with the retrieval system of memory rather than the storage system (see Figure 2). Whereas, problem-oriented simulations may improve the latter, complex problem simulations focus on the improvement of the former. The assumption in complex problem simulations is that the student has acquired sufficient knowledge to proceed in the development of thinking strategies employing the cognitive processes of differentiation and integration (and, perhaps in creating knowledge).

Because I am interested from an educational perspective in both the acquisition of knowledge and the improvement of cognitive abilities for problem solving, I have approached the design of an instructional strategy for enhancing higher-order thinking strategies development from a total curricular and instructional system (Seidel & Stolurow, 1980). That is, instead of viewing the learning of higher-order thinking strategies as being independent from other conditions of learning, I have made it an integral component of the Minnesota Adaptive Instructional System (MAIS). As with the other instructional variables and conditions of the MAIS, the complex problem simulation technique presented here can be applied in other instructional systems other than the MAIS. To illustrate the relationship of higher-order thinking strategies to knowledge acquisition, I will briefly review the MAIS.

MAIS environment. The MAIS is basically a computer-based research tool in which we have investigated instructional variables associated with improving learning according to individual differences and needs. As such, the instructional variables are represented in adaptive instructional strategies that in turn are monitored for each student by a expert tutor system using artificial intelligence techniques (Tennyson, 1987). Figure 3 illustrates the main components of the MAIS.

Insert Figure 3 about here

Briefly, the MAIS consists of two main components: (a) a curriculum component (or Macro), which maintains a student model (i.e., the cognitive, affective, and memory models of each student) and a curricular level knowledge base. An expert tutor system manages the Macro to maintain the student model and to select the appropriate information to be learned; and (b) an

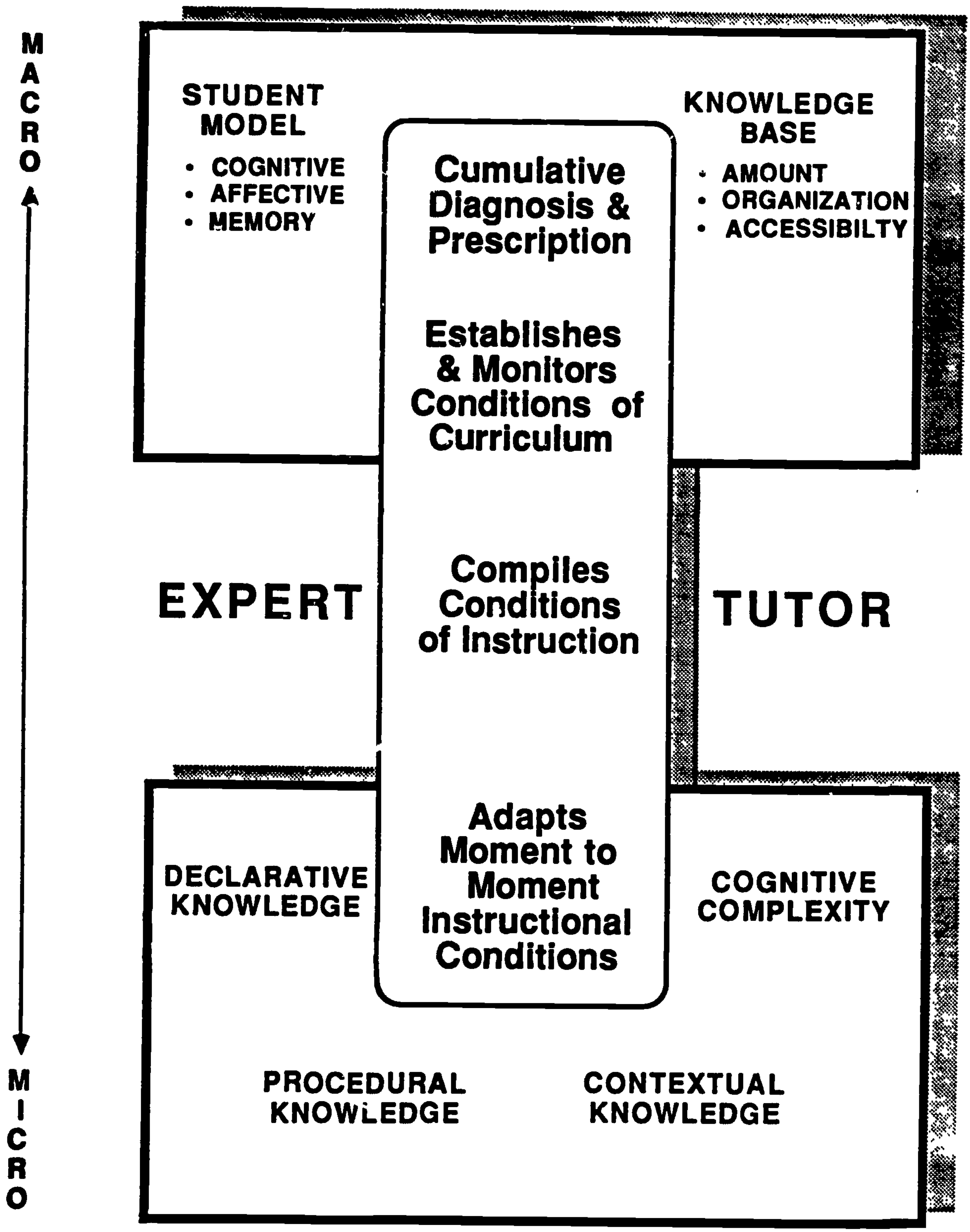


Diagram of the MAIS Environment.

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instructional component (or Micro) that adapts the instructional strategies according to moment-to-moment learning progress and need.

The Micro is likewise managed by an expert tutor system that monitors each student's given learning need. The instructional strategies for the Micro are compiled based on the data from the Macro. As the student progresses through a given curriculum, the Macro data base is iteratively updated, which improves the refinement of the expert tutor decision making within each component.

The instructional strategies are compiled using Gagne's (1985) three conditions of learning: verbal information, intellectual skills, and cognitive strategies. The first two conditions represent the acquisition of knowledge (i.e., the storage system) while the third is associated with the learning of higher-order thinking strategies. Tennyson and Christensen (1988) present the instructional methods for acquisition of intellectual skills (i.e., the learning of declarative, procedural, and contextual knowledge), while in this paper I present the instructional strategy for the cognitive strategies condition of learning.

Simulation Design

The goal of our research in the area of higher-order thinking strategies is to investigate instructional variables that improve student employment of the cognitive processes of differentiation and integration. To accomplish this goal, we have tested instructional methods that have the following kinds of characteristics:

-Situations that themselves have a meaningful context (i.e., not a game) that require the students to use their own knowledge base;

-Complex situations to challenge the differentiation process;

-Exposes students to alternative solutions to improve their integration process;

-Students see challenging alternatives within each student's own level of cognitive complexity;

-Environmentally meaningful situations to develop values;

-Situations that use reflective evaluation rather than right or wrong answers to develop higher-order criteria;

-Situations that allow students to see consequences of their solutions and decisions;

-Situations that allow for predicting value of future states;

-Situations that allow for continuous development of higher-order thinking strategies.

Unlike conventional computer-based simulations, complex problem simulations do not necessarily employ the computer as the instructional delivery system. The main purpose of the computer in our design strategy is to manage (and, in the MAIS environment, to monitor) the simulation with the student doing most of the learning activities with resources other than the computer. Depending on the learning situation, the computer could certainly be used as a learning and instructional resource. For example, in flight training, the flight simulator could be used for the improvement of trainee higher-order thinking strategies following the design variables defined below. Most likely, this form of learning higher-order thinking strategies as contrasted to acquisition of knowledge would be a more effective use of flight simulators.

The design conditions of complex problem simulations are grouped under three main components: necessary knowledge, simulation, and learning environment.

Necessary knowledge. An important aspect in developing and improving higher-order thinking strategies is to make sure that the students have the necessary knowledge base to begin the complex problem simulation. Necessary knowledge includes the specific domain's declarative, procedural, and contextual knowledge. That is, it is within the student's own knowledge base that the student will perform the cognitive processes of differentiation and integration. Without the domain's necessary knowledge as prerequisite, the student will not be able to fully develop and/or improve their thinking strategies because there is no knowledge to differentiate and integrate. For example, in a system like LOGO which does not have a specifically defined domain of knowledge, students always come up with the same finite set of figures: usually coming from associated domains of knowledge.

Simulation. This design variable consists of two parts. The first establishes the problem situation while the second is the computer management system. The problem situation should include the characteristics listed above. In addition to those, the simulation should be longitudinal, allowing for increasing difficulty of the situation as well as providing the adding and dropping of variables and conditions. In more sophisticated simulations these alterations and changes should be done according to individual differences. Also, the kinds of intelligences should be considered within the curriculum plans.

The main functions of the computer-based management part of the simulation are: (a) to present the initial conditions of the situation; (b) to assess the student's proposed solution; and (c) to establish the next iteration of the conditions based on the cumulative efforts of the student.

Learning environment. To further enhance the development and improvement of higher-order thinking strategies, I am proposing the employment of cooperative learning methods. Current research findings on cooperative learning indicate significant improvement in the learning of information (i.e., storage system) when intra-group members help each other in goal attainment (for a complete review see Johnson & Johnson, 1987). Our own most recent research (Breuer, 1985, 1987) shows cooperative learning methods as improving problem solving strategies.

The research findings indicate that intra-group interactions in problem-solving situations contribute to cognitive complexity development because the students are confronted with the different interpretations of the given simulation conditions by the other group members. In this way new integrations between existing concepts within and between schemata can be established, alternative integrations to a given situation can be detected, and criteria for judging their validity can be developed.

An important issue in cooperative learning is the procedure used to group students. Most often, when cooperative learning groups are used for knowledge acquisition, the students are organized according to heterogeneous variables, such as gender, socio-economic, intelligence and achievement. However, our research shows that for development of thinking strategies, group membership should be on similarity of ability in cognitive complexity. That is, within groups, students should be confronted with solution proposals that are neither too much above or below their own levels of complexity.

For example, students with low cognitive complexity become frustrated and confused with highly sophisticated solutions, while students with high cognitive complexity are not only not challenged but become quickly bored with less sophisticated solutions.

The format of the group activity should employ a controversy method where a consensus is reached following a discussion of proposals independently developed and advocated by each member. This format is in contrast to the compliance method where a consensus is reached by members working together from the start.

The controversy method can be explained in the following steps:

1. The problem situation is presented to the students. The computer-based simulation prints out the initial conditions of the situation.
2. The students on an individual basis study the situation and prepare an independent proposal.
3. The students reassemble as a group to present their proposals. In the initial presentation, the students are to advocate their position.
4. Following the initial presentations, the students are to continue advocacy of their proposals in a debate fashion. The concept of the controversy method is used to help the students further elaborate their positions as well as seeing possible extensions and alternations.
5. The final goal of the group session is to prepare a cooperative proposal to input into the simulation. This consensus is reached only after a complete debate and should represent the group's "best" solution.

6. The computer program will then update the situation according to the variables and conditions of the simulation. The steps are then repeated until the completion of simulation.

In summary, complex problem simulations are designed to provide a learning environment in which students develop and improve higher-order thinking strategies by engaging in situations that require the employment of their knowledge base in the service of problem solving. In the final section I present examples of several of the simulations developed for our research and later converted to software products.

Software Examples

Complex problem simulations which were developed in Germany and the United States include the following:

- -The economic system of a municipality which is to be improved by the "town council."
- -The microeconomic system of a company which is to be run by a "manager."
- -The flood control-system within a county which is to be operated by an "executive."
- -The living conditions of an African tribe which should be improved by an "advisor."
- -The efficiency of fuel and energy consumption to meet modern-day needs.

In each of these situations, a set of materials were prepared in which the necessary knowledge was presented. The students were taught the information by both teacher presentations and print materials. After all students had learned the necessary knowledge they were assigned to a group based on similarity of cognitive complexity.

Each of the simulations represented dynamic situations. That is, they depicted situations that, without actions from the decision-makers, would collapse after a certain time period. For example, the tribe vanishes because of starvation, the company goes into the red, and so forth. Each of the simulations stressed the need for decision-making and the proposals required solutions that included cognitive conflicts.

The simulations were complex and longitudinal so that after each period of decision-making, the new status of the situation was reported to the students. This allowed the students to test the adequacy of their most current conceptualizations of the situation with the updated conditions, and usually resulted in the need for revisions. In addition, because of the open definitions of the situations in terms of global goals, the level of thinking remained high, preventing the mere recall of information.

In summary, the complex problem simulations which we have developed have shown significant improvements in the development of higher-order thinking strategies. That is, there were measurable increases in the cognitive processes of differentiation and integration.

Conclusion

The learning principle underlining our research program is that thinking strategies are acquired in reference to employment of the learner's own knowledge base and that they are not independent thinking skills. Our instructional principle is that, because cognitive complexity is an ability, it can be developed and improved with instructional intervention. Therefore, the goal of our research program is to study instructional variables within the context of an instructional system that takes into account both the storage and retrieval systems of long-term memory. The MAIS environment provides this opportunity because of direct concern for both curriculum and instruction and for all conditions of learning.

As this paper indicates, complex problem simulations focus on the improvement and development of higher-order thinking strategies (i.e., problem solving within the context of employing the knowledge base). We are continuing research at this level while future efforts will also include direct investigations at the creativity level. We anticipate that learning activities at that highest level will be more directed towards increased individual efforts with group activities geared more at critical analysis than consensus.

The influence of intelligence in the entire process of higher-order thinking is another problem area for our future research. We anticipate a high correlation between cognitive ability and intelligence, but perhaps will see other variables interacting in the cognitive process: such as criteria and values development and achievement motivation. Psychologist have long recognized that higher-order thinking strategies involve more than just acquisition of cognitive skills, but other variables and conditions of the total human system.

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