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ABSTRACT

Third in a series of six monographs on the use of new technologies in the instruction of learning disabled students, the paper explores program design strategies for computer-based instructional materials. Section 1 summarizes ideas related to models of perception and cognition, theories of instruction, and key characteristics of intelligent technologies. Section 2 analyzes the instructional effectiveness of two specific pieces of effective educational software ("Mastertype" and "Spelling Bee Games'" in terms of the ideas developed in Section 1. A final section discusses implications of these ideas for future research on the design of computer-based instruction. (JW)

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The Learning Disabled and Computer Based Education: Program Design Strategies

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CREATE Monograph Series

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I. OVERVIEW

CREATE (The Center for Research and Evaluation in the application of Technology to Education) has been funded by the Special Education Programs Office of the Federal Department of Education to investigate how new technologies can be used effectively in the instruction of handicapped students. Within this very broad area, CREATE will focus on the learning disabled students, and on the use of widespread "intelligent technologies" including microcomputers and associated peripheral equipment such as pointing devices (touchpads, mouse(s), light-pens, etc.).

The research agenda of CREATE is expected to span at least four years. This paper, one of six to be prepared in the first project year, is an outcome of the initial literature review and project planning of the CREATE staff. Its subject is strategies for computer instruction, and it reflects our attempt to identify a tentative set of principles for the design of computer-based instructional materials for the learning disabled. These principles will guide our development of prototype materials that will be examined and evaluated through school-based trials.

At the outset it is important to be specific about what is meant by a strategy for computer instruction. It is a systematic plan for the use of intelligent technologies to accomplish a specific instructional goal. Ideally, such a plan is based on a thorough understanding of how individuals learn best, coupled with a parallel understanding of how to organize and present instruction to optimally fit the way individuals learn. However, despite increasing attention by instructional and cognitive psychologists, we are still, as Jerome Bruner put it in 1966, lacking a compelling "theory of instruction as a guide to pedagogy -- a prescriptive theory on how to proceed in order to achieve various results, a theory that is neutral with respect to ends but exhaustive with respect to means" (p. 31).

Even though a solid foundation of theory is not available as a guide, there is a substantial body of research on perception and cognition that has important implications for the development of instructional strategies. While developing computer-based materials the CREATE staff will have opportunities to translate these implications into research hypotheses about insructional design, and test them in school settings. Our primary interest will not be to extend theory for theory-building sake. Our primary interest is application of theory. Our aim is twofold: to identify and demonstrate effective instructional strategies, and to influence developers of instructional materials to incorporate those strategies for the benefit of handicapped learners.

The distinction of purpose between pure and applied research has had important implications for both the style of research we have decided to engage in, and for the ideas we will present in this paper. Our approach is eclectic. We have sought promising ideas for strategies in the research literature, but have also carefully evaluated the subjective assessments of practitioners regarding strategies that they see as likely to work.

This paper is divided into three main sections. The first provides a summary of ideas that have emerged from our initial literature review and from discussions with practitioners. These ideas are related to a) models of perception and cognition, b) "theories" of instruction, and c) key characteriscics of intelligent technologies.

The second section discusses selected software that appears to be effective when used with learning disabled students, and suggests explanations for its effectiveness in terms of the ideas developed in the first section.

The paper concludes with a summary of how these ideas will influence the directions our research will take over the next few years.

II. PERCEPTION, COGNITION, INSTRUCTIONAL THEORY and COMPUTERS

A. The Implications of Theories of Perception and Cognition for the Design of Instructional Materials.

For the last fifteen years a great deal of research on perception and cognition has been undertaken within a common family of theoretical frameworks referred to as information processing theories. Within these theories, conceptual distinctions are made among input, processing, and output stages of cognition, although the terms that are used to label these stages vary.

Within each stage, processes are further subdivided. For example, LaBerge and Samuels (1974) have described processes characterizing the input stage as involving:

1) initial detection -- inputs from multiple sensory surfaces are captured by sensory detectors,
2) selection and filtering -- the selection of relevant features from stimulus patterns for further processing,
3) coding -- the construction of codes from the relevant features that can be compactly stored and efficiently retrieved from memory structures, and
4) short-term memory -- "the temporary grouping of a limited number of codes in episodic memory."

We will refer to input-level skills as enabling skills, since efficient input-level skills are essential to enable individuals to perform higher-level processes effectively.

Similarly, the processing stage has been described as containing constituent processes such as categorizing, recalling, comparing, sorting, relating, interpreting, synthesizing, extrapolating and others. We will refer to these higher order skills as processing skills. In contrast to input level processes which have been assembled into "flow models" by a number of researchers, higher level cognitive processes have, for the most part, been viewed as either too complex or not understood enough to organize in similar fashion. Subsets of higher cognitive processes, such as those involved in general problem solving, have been represented using computer models (e.g. Newell and Simon, 1972). Those involved in analogical reasoning have been experimentally examined and statistically modeled (e.g. Sternberg, 1977).

Less attention has been given to the output stage of information processing, although Feuerstein (1980) has made important contributions in examining and remediating dysfunctions among learning disabled youngsters associated with the output stage. He has argued that problems associated with output often involve blocking, inadequate impulse for precision and accuracy, and trial and error response styles. In CREATE, we will use the term <u>performance skills</u> to signify information processing outputs of an academic nature, such as spelling, reading, and math computation.

The research and development activities of CREATE will be conducted within the information processing framework. Das, Kirby, and Jarman (1979) point out a key advantage to adopting an information processing approach to the study of learning disabilities:

> It makes one relate performance to cognitive processes and hence facilitates the development of remedial measures. Because it is based upon a general model of cognition, an information-processing approach to learning disabilities would tend to suggest remediation that has a firmer theoretical rationale (pg. 101).

Two prominent educational psychologists, Gagne and Briggs, have related their theory of instruction to information processing models of cognition (1979). They list the key cognitive processes as attention, selective (feature) perception, short-term memory, rehearsal, long-term memory storage, and retrieval. Gagne and Briggs argue that effective instruction should support these processes of learning and suggest a sequence of instructional events including: (a) gaining attention, (b) informing the learner of the objective, (c) stimulating recall of prerequisites, (d) presenting the stimulus material, (e) providing "learning guidance", (f) eliciting the performance, (g) providing feedback, (h) assessing the performance, and (i) enhancing retention and transfer. (c.f. Gagne & Dick, 1983).

Because information processing approaches to cognition have so dominated recent research, they provide a perspective that can be used to structure research and develop areas of consensus among the researchers. Finding areas of consensus is an important goal of our research and development approach. Planning for any long-term research effort involves allocating scarce resources across alternative investigations. To maximize the likelihood of investing in studies that will pay off, we will concentrate on areas that most cognitive psychologists would agree are of critical importance for effective learning and, at the same time, are the likely loci of the cognitive dysfunctions that characterize the learning disabled.

Let us, therefore, focus in more detail on those aspects of information processing that can contribute substantially to the remediation of learning disabilites and lend themselves to computer-related applied research. Three critical topics will serve to organize this discussion: (1) assumptions of limited capacity underlying information processing models, (2) automatic versus controlled processes, and (3) the relationship between "meta-cognition" and controlled processes.

Limited capacity assumptions. One assumption underlying models of information processing is that individuals are limited in their capacity to process information. For example, there is a limited number of variables that an individual can simultaneously keep track of. George Miller's well-known 1956 paper suggesting seven variables, plus or minus two, remains credible. Similarly, there is a finite number of sensory inputs that the mind can simultaneously process.

Mulder (1983) distinguishes among three main theoretical interpretations of how such capacity limits affect processing. Those who view processing as occurring through a set of sequential stages argue that any highly demanding processing task will exhaust processing capacity at the stage which requires the most mental effort. In other words, overall processing can be no more rapid than the processing occurring at the least efficient stage in the process. Short term memory, for example, has been identified by Shiffrin (1975) and Shiffrin and Schneider (1977) as requiring relatively large amounts of capacity, and can be thought of as often creating a processing bottleneck.

A second perspective, exemplified best by Kahneman (1973), views processing as involving parallel perceptual and cognitive tasks, each consuming a share of processing capacity. Presumably, processing capacity, drawn from a single "pool", is allocated across tasks. The greater the demands on capacity by one task, the less the available capacity for other tasks.

The third approach views capacity as available from multiple pools, each associated with some internal processing mechanism. One or more mechanisms may exhaust the capacity of its associated pool, thereby limiting the amount of information that can be processed (Mulder, 1983).

From the information processing perspective, dysfunctions related to individual capacity limits are natural candidates for explaining numerous kinds of learning disabilities. Is the child who slowly decodes prose phonetically without comprehending its meaning actually exhausting processing capacity on the decoding task, leaving no excess capacity for semantic analysis? If so, are there inefficiencies in this child's phonetic decoding process that can be rectified, freeing capacity for parallel tasks of interpretation? Is the distractible child exhausting processing capacity due to an inability to screen out those stimuli that are irrelevant to assigned tasks? If so, are there dysfunctions in the child's ability to efficiently discriminate foreground and background information in one or more sensory modality? Might such inefficiencies be remedied through discrimination training?

Automatic versus controlled processes. Researchers make a qualitative distinction between two types of information processing. One is more active, requiring mental effort, the other more passive. Controlled processes have been referred to as active in nature, highly demanding of processing capacity, and highly flexible. Passive processes are referred to as automatic, and are believed to be either biologically fixed (i.e., species characteristics--built into the system) or learned through considerable training (Hasher & Zacks, 1979, Mulder, 1983). Blinking in response to air blown into one's eye is a biologically fixed automatic response. Manipulating a pen when writing can become automatic through massed practice. Many theorists believe that automatic processes require little or no processing capacity. If capacity requirements do exist, they are likely to be small relative to those of controlled processes.

Controlled processes, including those cognitive processes mentioned above--categorizing, recalling, comparing, etc.--are influenced by individual differences in intelligence, culture, education and early experiences (Hasher & Zacks, 1979). Hunt (1978) suggests that cognitive differences may in turn be related to differences in automatic processing efficiency. Individuals with less efficient automatic processes have to work harder at learning tasks involving verbal information, for example. And, over time, the effects of this handicap could accumulate and lead to large individual differences in verbal skill and knowledge (Resnick, 1981)

Schneider and Shiffrin (1977) argue that some controlled processes can become more automatic with extensive practice. Thus, individuals can learn to perform complex operations with only minimal processing capacity being allocated to them. LaBerge and Samuels (1974) view skilled reading as such a process, possible only if the necessary component processes can be made automatic, as they must be quickly and accurately coordinated. If all the component processes required attention, attentional capacity would become overloaded and result in performance deficits. It may be difficult for students to learn to make the component processes automatic (often requiring "massed practice"), nevertheless, "when decoding and comprehension processes are automatic, reading appears to be 'easy', and when they require attention reading appears to be 'difficult'".

Metacognition and controlled processes. Metacognition involves the monitoring and regulation of information processing strategies (Lawson, 1980). Recent interest in metacognition has focused on questions of whether or not individuals can be beneficially taught to consciously monitor and regulate their own controlled processes. Metacognition includes the deliberate selection of one strategy from among alternatives to use in solving a problem. It also includes an individual's self-monitoring during problem-solving, in order to assess the effectiveness of the problem-solving strategy and switch to a new one if necessary.

Similarly, deliberate use of memory-aiding schemes, either for storage or retrieval of information, fall within an area of metacognition that has been referred to as metamemory. The concept that individuals can develop general-purpose high-level cognitive processes to increase the effectiveness of other cognitive processes is not new. Most information processing models of cognition dating back to the work of Miller, Galanter and Pribram (1960) make some provision for these "executive" processes. Yet only recently has interest grown in teaching metacognitive strategies to the learning disabled, to help them monitor and adjust their own cognitive styles.

Wein (1983), for example, hypothesizes that learning disabled adolescents do not use appropriate (or efficient) strategies due to a lack of motivation, and that this is the result of a poor self-concept. He contends that if these students can be taught to think more effectively, they will become more motivated to learn. "An intent to learn develops and feeds the ability to learn and vice versa" (p. 145). The learned helplessness of the learning disabled adolescent is said to interfere, therefore, with the normal development of metacognitive skills. Wein believes that teaching metacognitive skills directly may be an effective remedial approach for these individuals. He proposes training approaches based on the work of Brown (1978) and Flavell (1978) which would teach such skills as:

1) recognizing problem difficulty,
2) using inferential reasoning to check the validity of information,
3) predicting the outcomes of strategy use,
4) predicting task difficulty,
5) planning study-time needs,
6) monitoring the success of strategies,
7) checking outcomes for internal inconsistency, and
8) checking outcomes against common sense criteria (reality testing).

Brown and Alford (1984) developed a cognitive self-instructional training program where learning disabled children with attentional deficits were taught to attend to visual discrimination problems more efficiently. Two months of training consisted of:

1) match-to sample,
2) component analysis training (breaking a word into its component parts),
3) detail analysis training (identification of detailed components of a picture),
4) memory tasks (recall of picture and details), and
5) visual sequence training (assembly of comic strips into the final assembled comic, paying attention to the rationale of each part of the comic).

Brown and Alford requested the students to verbalize the strategies they employed throughout the exercises. All the exercises used a self-verification procedure in which the students were encouraged to stop and define a problem, while considering and evaluating several possible solutions. The results showed improvement in reading (a grade level). However there was no transfer to other tested areas including spelling and arithmetic.

To this point we have discussed aspects of enabling and processing skills that suggest some plausible sources of learning disabilities. Dysfunctions may be located within particular perceptual or cognitive processes, resulting in requirements for excessive processing capacity. This could result in a net loss of capacity available to other processes. Moreover, such dysfunctions might appear as controlled processes (labored decoding in reading) when they need to be automatic. The most suitable remediation in these cases may well be a combination of targeted training (to replace inefficient strategies with efficient ones) and massed practice (to integrate new processes into a response system that will function automatically). We will discuss later, and in some detail, ways in which computers are well suited to the identification and remediation of dysfunctional processes associated with both enabling and processing skills. Finally, we introduced the topic of metacognition and suggested that instruction in metacognitive strategies might also benefit learning disabled students. Having identified these basic <u>targets</u> of instruction it is important to examine methods that might be used. Initially, we will turn to a brief review of current perspectives on instructional theory.

B. Perspectives on Instructional Theory

Perspectives on the best way to provide instruction vary considerably. For the most part, variations reflect differing views on: (1) the importance of individual learner differences in terms of ability level and stage of cognitive development, and (2) the necessity of adopting differing instructional strategies depending upon the nature of the subject matter being taught. Yet there are also areas of substantial consensus, to which we look for principles to guide our research and development. Much of the information summarized here is drawn from an excellent review of instructional psychology by Gagne and Dick (1983).

In an instructional context, learning is thought to occur to the extent that the learner demonstrates acquisition of appropriate responses to particular stimulus conditions. In order for individuals to be able to make new responses, prerequisite knowledge is usually required. As a result, one question faced by many instructional theorists is how to ensure that knowledge that is prerequisite for a particular type of instruction is "in place" before that instruction is provided. Of special interest, therefore, is how an instructional sequence should be constructed.

Reigeluth and Rodgers (1980) suggest that the organization of instructional sequences be guided by the following steps:

1) select all the operations to be taught (by performing a task analysis),
2) decide which operation to teach first (choosing those prerequisite to other operations to be taught),
3) sequence the remaining operations in the same way,
4) identify the supporting content,
5) allocate all content to lessons,
6) sequence the instruction within each lesson, and
7) design the instruction for each lesson.

Markle and Tiemann, who have elaborated the principles of programmed instruction (1974), place similar stress on the importance of hierarchical organization of instructional sequences. The implications of this for remedial instruction are clear. Where individuals are unable to perform complex tasks, remediation should occur first with the performance deficits lowest in the hierarchy, so that abilities that are prerequisite to the acquisition of higher abilities will be acquired first.

Yet it is rarely the case that remedial training follows this precept. A child who is unable to read well at a particular grade level is typically assigned easier reading materials. But since reading problems often appear when information processing capacity is exhausted by inefficient underlying processes (such as poor cue recognition), more practice at easier reading levels is unlikely to solve such problems. Instead, the inefficient process itself should be the target of focused training (Kirby, 1980).

Theorists concerned with single units of instruction (rather than sequences) also address the issue of prerequisite knowledge. Gagne and Briggs (1979), for example, recommend that early in each instructional unit an attempt be made to stimulate recall of prerequisites. This presumes, of course, that all learners receiving instruction have been exposed to prerequisites. In contrast, Collins (1977) has conceived of a system labeled Socratic Tutoring. The instructional materials themselves contain probes that test the learner's understanding of the body of knowledge in order to determine the level at which instruction should begin.

Engaging learners and sustaining their interest is a key requirement for effective instruction, although not often explicitly incorporated in theories of instruction. Merrill, Richards, Schmidt and Wood (1977) include "attention focusing" among the instructional strategies they discuss. Gagne and Briggs (1977) identify "gaining attention" as the initial step in an instructional unit.

A topic of considerable interest is how to most effectively guide a learner in generating an appropriate response when stimulus conditions occur. Responding appropriately requires recognizing the stimulus conditions, and then having the ability to generate the response. Modeling and demonstration are two recommended techniques of instruction when new response abilities are being taught (Haring, 1974). But what are the characteristics of good demonstrations and models?

Bruner, building upon the work both of developmental psychologists such as Jean Piaget and innovative educators such as Maria Montessori, argues that as children develop they first learn through manipulation of concrete objects in their environment, then through mental manipulation of images of their environment, and finally through symbols that represent objects or relationships among objects. "Any domain of knowledge (or problem within that domain of knowledge) can be represented in three ways: by a set of actions appropriate for achieving a certain result (enactive representation); by a set of summary images or graphics that stand for a concept without defining it fully (iconic representation); and by a set of symbolic or logical propositions drawn from a symbol system that is governed by rules or laws for forming and transforming propositions (symbolic representation)" (Bruner, 1966 p. 44). He suggests that the most effective demonstrations and models often represent knowlege to be learned in all three ways, thus allowing the learner to work at the multiple levels, depending upon which they are most comfortable with. Even as individuals acquire more powerful learning modes--symbolic versus iconic--they can fall back upon less powerful but sometimes more dependable styles as needed.

According to Bruner, good models and demonstrations convey knowledge with economy and power. An economical model minimizes the amount of information the learner must hold in mind when performing a cognitive task, in order to achieve comprehension. The power of a model is its capacity to allow the learner to comprehend diverse aspects of a problem situation.

Case (1978), stresses the importance of models and demonstrations that minimize cognitive complexity, especially for children whose stage of intellectual development has not yet established higher level cognitive abilities. Thus, where there is a tradeoff of economy and power, Case would presumably favor economy.

Rothkopf (1981) focuses on the disparity between the desired learner performance, and the model or demonstration used in instruction. Any disparity requires interpretation and conceptual transformation by the learner. In many subject areas, most obviously mathematics and science, principles are taught by example, and learners are expected to apply them in new contexts. Presenting instruction so that generalization of this kind is facilitated (consistent with Bruner's concept of power in models) has also been the subject of attention of a number of instructional psychologists.

Scandura (1980) and Landa (1976) have both addressed the question of improving learners'ability to apply principles in new contexts. Scandura's "structural learning theory" is most easily understood as a theory of rule learning and application. Scandura emphasizes the importance of teaching: (1) how to identify those aspects of a "problem" situation that serve as cues announcing that a rule or set of rules should be applied, (2) how to apply the rule(s), and (3) how to evaluate the results to determine whether or not they are reasonable and acceptable. Extensions of structural learning theory also suggest ways learners should respond if the rules they apply produce unreasonable results.

Landa (1976) views sets of rules as "algorithms", and has identified the characteristics of good algorithms as well as procedures for teaching them. According to Landa, algorithms are "specific", meaning that all actions a learner needs to perform are determined by the algorithm. But they are also "general", meaning that they can be applied to a class of problems. Finally, the algorithms are always to be applied deliberately, when seeking results of a pre-determined kind.

Other instructional psychologists have focused on questions of how to provide learners with the practice that will enhance their ability to generalize learning appropriately. Merrill et al. (1977) suggest a number of strategies, including adequately sampling instances where the learner appropriately generalizes a response, presenting instances where generalization is inappropriate, and designing these instances so that the aspects of them that make them appropriate or inappropriate are easily contrasted and identifiable. Gagne and Briggs (1979) also include enhancing retention and transfer as a key component of their recommended instructional sequence.

The final two components of effective instruction that cannot be overlooked, and that are of critical importance, are corrective feedback and practice. Recognition of their importance is widespread among educators, learning theorists, and instructional psychologists.

Let us summarize briefly the key ideas we have drawn from the literature of instructional psychology. First, instruction should be directed to that (or those) points in a learner's hierarchy of knowledge and abilities where prerequisites for new learning do not exist. Second, engagement, focusing of attention and motivation are critical to successful instruction. Third, demonstrations and models should convey the desired learner performance well, that is, maximizing comprehensibility, power, economy and similarity to the desired performance. Fourth, instruction should be designed to enhance the probability of appropriate generalization and transfer. Finally, instruction should include opportunities for practice with corrective feedback.

C. Key Characteristics of Intelligent Technologies for Instructional Design

The preceding discussion identified two general targets of instruction for those with learning disabilities: (1) input processes that are inefficient and make excessive demands on available processing capacity, and (2) metacognitive processes that, if developed, would help learners to exercise better control over other cognitive processes.

Instructional methods were also discussed, focusing, in particular, on the literature of instructional psychology and those methods that merit application in the design of instructional computer-based programs. Here, we will examine the characteristics of microcomputer and related technologies that can be used to advantage in applying those methods to reach the targets.

We begin with a general concept of what the new technologies are. At the heart of a computer-based system is a microprocessor that can be thought of as a very fast, general purpose, branching machine. By branching machine, we mean that it will perform different functions depending upon the conditions it encounters. By general purpose, we mean that both the functions it performs and the conditions that cause it to perform a particular function (or another) can be predetermined by an instructional designer or a programmer; thus the particular purpose served by the microprocessor is entirely "assignable". A microcomputer system (the heart of which is a microprocessor) obtains information about conditions from "input devices." The functions it performs are perceived by users through the microprocessor's control of "output devices."

It is important to begin with this very general concept, for although most microcomputers systems in use today are comprised, from the learner's perspective, of keyboard input devices and video-monitor output devices, systems dedicated to particular purposes may be far more effective with different configurations of input and output devices, as well as with more creative uses of keyboards and monitors.

Therefore, in considering the potential uses of this technology, microcomputer systems can be best thought of as multi-media information presentation devices. And while visual and auditory modes of communication come to mind first, the tactile mode, used to great advantage at the preschool and primary levels, can be incorporated in computer-based instruction using touch-pads, touch-screens, and various kinds of robotic devices.

Even though this technology is extremely versatile as a multi-media presentation device, its most potentially powerful characteristic, and the one that causes the term "intelligent" to be applied to it, is its "adjustability". Because of its inherent branching capability, a microcomputer program can automatically adjust itself to better suit the needs of an individual learner. Some of the presentation and response variables that can be changed while (or before) a program is running are (1) its level of difficulty, (2) the extent of remediation given, (3) program pacing, (4) frequency of reinforcement, and (5) the use of motivating elements such as game features.

But how can this extraordinary versatility best be used? Research to date suggests that it should be used to accomplish two main objectives: (1) to provide attractive opportunities for practice, and (2) to provide targeted adaptive instruction. The first objective relates directly to the importance of both learner motivation and practice. The second relates to the importance of models and demonstrations that are minimally disparate from the desired performance and that are comprehensible, economical, and powerful.

Attractive opportunities for practice. The ideas presented here are based, in large measure, on Thomas Malone's study of intrinsic motivation in computer games, What Makes Things Fun to Learn? (1980). Malone's work is based on a combination of survey research, experimental investigations of variants of the same computer game, and a review of theories of learning and instruction. Piaget provided Malone the basic elements of a theory of intrinsic motivation; "people are driven by a will to mastery (challenge) to seek optimally informative environments (curiosity) which they assimilate, in part, using schemas from other contexts (fantasy)" (page 49). Malone then expands upon each of these categories of appeal, using various microcomputer games as examples.

A successful microcomputer game generates a challenging "environment," one in which the learner wants to attain a goal, senses that it is possible and makes progress, but cannot attain the goal easily. Often, goals are desirable because games involve elements of fantasy. The learner who can "suspend disbelief" and see him or herself defending a space station against alien invaders is more likely to get caught up in a game, thereby increasing skill in shooting down the invaders, than one who does not find this fantasy appealing. Progress in developing skills itself becomes motivating, so that the ability to fantasize makes the player more skillful, and their skillfulness and success deepens the sense of fantasy.

Various techniques are used to keep the attainment of goals from being too easy. Random stimulus conditions help to keep them from becoming repetitive and predictable. Difficulty levels are adjusted as the player becomes more expert, so that they must always strive to be successful. The information presented to the player is often imperfect (e.g., images on the screen that they must respond to may suddenly appear after being hidden from view).

Progress must be possible so that games are not entirely frustrating. Often intermediate goals are accomplished as ultimate goals are pursued. These are rewarded with noticeable changes in visual format of the game, as well as increases in the difficulty level, so that it is clear to the player that a new level of skillfulness has been reached.

Malone distinguishes between sensory curiosity and cognitive curiosity. Sensory curiosity describes the impulse of players of computer games (or viewers of television, for that matter) to respond to certain kinds of auditory or visual patterns by focusing attention on those patterns. This appears to be clearest in computer displays when the perceived foreground information changes at a rate that allows interpretation within the limits of information processing capacity, but that could not be interpreted without continual attention. Such displays are initially attractive and they compel attention. An object apparently moving toward the player in three-dimensional space has this quality. An object moving across the screen and changing in shape is another example. Sensory curiosity is often enhanced in computer games with changes in auditory information that fits the transformations occurring in visually displayed information.

Cognitive curiosity is enhanced by allowing game players to perceive that they have a near but not complete understanding of the structure or patterns within the game. This appears to appeal to a motivation to acquire a little bit more information to complete the understanding. By adjusting games to introduce new inconsistencies in the players' knowledge, cognitive curiosity can be maintained.

Targeted adaptive instruction. Targeted instruction focuses as narrowly as possible on the specific performance skills or knowledge required of the learner. If an instructional objective is to improve a learner's ability to discriminate easily rotated or reversed letters (i.e., t and f, m and w, b and p), a traditional approach might be to have a learner practice writing them. This task requires more than the visual discrimination ability selected as the target of instruction. A learner who has poor writing skills may be discouraged by messy letter production caused by poor small motor control, and this discouragement may markedly decrease the effectiveness of handwriting practice as a means to improve letter discrimination ability.

Computers lend themselves to managing such discrimination tasks in a more narrowly targeted way. A display with a touch-sensitive screen could be used to directly assess whether a learner had made an appropriate discrimination. Moreover, the computer program could direct attention to those aspects of letters that make them discriminable. A "u" shape, for example, would "trap rain," while it would "run off" an "n" shape. Computer animation that showed this (to make discrimination easier) might enable students to be successful in the first levels of a letter discrimination game. At a higher difficulty level such hints would be removed.

Narrowly-targeted instruction of this sort may be critical in remediating certain kinds of learning disabilities. In cases where a constellation of related skills are weak, (visual discrimination skills for example), narrowly targeting some skills for remediation while minimizing the requirement that learners use other skills in the weak group may be essential. For example, if a learner has weaknesses in both shape discrimination and foreground/background discrimination, attempts to improve in one area may be greatly hindered by the weakness of the other. Only by making one type of discrimination very easy might the other one be improved through training.

Adaptive instruction presents material that is challenging to the learner. Good programs should adapt by evaluating the responses of learners to presentations. They can adapt by branching to targets where instruction is predicted to have the greatest payoff, after initially evaluating the learner's ability in each of the available instructional target areas. Once a target is selected, adaptive techniques can be used to ensure that material is neither too difficult nor too easy, and that difficulty is appropriately adjusted as the learner's skills improve.

Computers are well suited to providing practice opportunities in which the desired learner performance, once elicited, is improved through presentations that make the performance more challenging, as long as adequate skillfulness is maintained. Thus, enabling skills (e.g., discrimination, coding, attention focusing) are enhanced by requiring performance that is increasingly rapid, or that must be done despite more and more distractors. Processing skills (e.g., analogical reasoning, categorizing, applying principles) might be enhanced by requiring action that involves generalization or transfer to decreasingly obvious instances. Within this instructional framework, it is even possible to change models and exemplars that are provided to the learner from those that would be initially easy to understand but limited in power, to those more difficult to understand but, once acquired, might be more broadly useful.

The adaptiveness of software need not be done entirely automatically. In fact, limitations in the speed of microcomputers and in the amount of accessible memory constrain the amount of automatic adaptation that can be done. One alternative is to let educators preset presentation parameters before software is used by learners. Another alternative that may increase the learner's motivation is to let the learners themselves control some of the presentation parameters.

III. AN ANALYSIS OF TWO EXAMPLES OF EFFECTIVE SOFTWARE

We now turn to a brief analysis of two pieces of educational software, MasterType, by Lightning Software, and Spelling Bee Games by Edu-Ware. Both of these have been used successfully by teachers of the learning disabled that have been interviewed by CREATE staff. MasterType has also been favorably reviewed in a number of journals and magazines, including the Journal of Learning Disabilities (April, 1983). It should be noted that our purpose here is not to endorse these products. Both pieces have weaknesses as well as strengths. MasterType, for example, is built around a space attack theme which we recognize runs counter to the instructional philosophy of many educators. We have chosen these programs to discuss because they are well suited to an application of the ideas regarding targets of instruction, methods of instruction and characteristics of intelligent technologies that we have developed to this point.

MasterType was developed to teach touch typing skills on a computer keyboard. However, in doing so, it develops other important skills as well. At the center of the screen a "command ship" is displayed. The player defends the command ship against attacking ships that move steadily towards it from the corners of the screen. Each attacking ship contains single letters or a word that can be entered by the player from the keyboard. If the correct keystrokes occur before the attacking ship reaches the command ship, the attacking ship is destroyed. When an attacking ship is destroyed, a new ship, with a new letter or word to be typed, appears in the corner of the screen to replace it.

MasterType keeps students actively involved. The game format appeals to their sense of fantasy, and most learners, even those who have difficulty concentrating when information is presented using other media, pay close attention when playing. When children begin to play, they look from the screen to the keyboard to find the keys they need to press in order to destroy attacking ships. Later, some students are able to stop looking down at the keys, having developed automatic eye-hand coordination. In addition to eye-hand coordination, practice in visual tracking is provided as students follow the letters toward the center of the screen. The need for rapid decoding as the letters move also sharpens a constellation of visual discrimination skills.

Another factor that makes MasterType successful with learning disabled children is its provision for extra practice. The game is scored and students are motivated to improve their scores by the challenge inherent in the game, and by their observations that the more they play the better they become. As they elect to extend their practice, some learners see that practice itself is an effective learning strategy.

The game adapts to individual differences in two primary ways. First, the "word content" of the attacking ships (what the player must type) can be entered by the teacher. Thus, for learners with limited skills, letters instead of words can be practiced. Second, the difficulty of the game, which is determined by the rate at which the attacking ships move toward the command ship, can be set at a number of levels. Thus, the game can be adjusted so that it satisfies the conditions that make a game challenging, providing for intermediate goals that can be reached -- progress -- while ultimate goals continue to provide an incentive.

MasterType has graphic elements that appeal to both intellectual and visual curiosity. For example, correctly spelling the word leads to reinforcement as the ship explodes with a colorful display, synchronized with audio effects. A parallel appeal to cognitive curiosity is created as the player is about to complete keying in a word that is needed to destroy an attacker. The player knows that only one more letter needs to be typed, and this creates suspense--(Will it be done before the attack ship reaches the command ship?)--which is resolved in a satisfying way when the last key is pressed. The appeal to cognitive curiosity also exists at a higher level. Players are curious about the most effective strategy to use. The optimal strategy for defending the command ship is to destroy attacking ships by typing their words in a clockwise or counter-clockwise sequence. As players discover this strategy their reinforcement is their quickly increasing success in scoring points.

Several of the characteristics we have identified as desirable from an instructional point of view are absent from the game. In particular, corrective feedback is limited to the absence of the outcome the learner desires (an exploding attack ship) when an incorrect word is entered. There is no feedback to help the learner to understand why he or she is not being more successful. For example, learners often adopt awkward finger positions on the keyboard because of initial "hunt and peck" strategies of finding the correct keys. This may ultimately limit their maximum speed. Also, transfer of visual tracking skills to more typical reading contexts may not occur because of the unusual diagonal tracking that occurs in the game. Of course, it is possible that the addition of these features (in order to increase the soundness of the design from an instructional point of view) might decrease its engaging quality. The net effect might be a less effective product. Such tradeoffs suggest research efforts aimed at identifying optimal tradeoff points.

Another set of games (four, packaged together), are Spelling Bee Games. All operate on the same list of words, but each addresses different learning styles. As in MasterType, there is a teacher option to determine the work lists a student uses. The beginning level offers practice in spelling consonant/vowel/consonant (C-V-C) words, such as cat, bus, and net. More challenging lists can be chosen by the teacher to provide practice in other common spelling patterns such as C-V-C-C (tack, milk, lamp), or words with phonograms such as farm, barn, card. The teacher is in control of the difficulty level, while the student is able to choose one of the four games to practice the words the teacher has chosen.

For students who prefer the whole word approach, there is Squadron, and a Concentration-like game. In both activities, the player matches a whole word to a picture clue. Squadron is a fast paced game in which the player manipulates a joystick or game paddles to point airplanes to a correct word. The concentration game is slower-paced, and helps develop learners' memory skills.

Two other games require putting letters together in the correct order. One is fast paced, in which the player manipulates a helicopter to pick up letters one at a time and place them down in the correct order to spell a word. Only the letters needed to correctly spell the picture clue are there, enhancing the possibility of success on this task. In the fourth game, called Convoy, players spell words letter by letter and watch their trucks inch toward a finish line.

Teachers report that most students choose the same game each time they play, and that their choice appears to correspond to their preferred learning style in other academic tasks. Some of the games appeal to children who like the challenge of competition with someone else. Other games appeal to those who prefer to work by themselves. Thus one type of adaptation is handled by providing for learner control. The games include animation that is colorful and visually appealing. Three of the games provide for fantasy in the sense that the player becomes the pilot or driver of a vehicle.

The games have several supportive features that help to focus on the instructional target, building spelling skills. Visual cues in the games prompt players to spell words from left to right. There are also just enough spaces provided for the positioning of the letters in the words, facilitating their spatial organization on the screen, and reducing the need for learners to have well developed spatial abilities in order to neatly locate the letters in their correct positions. A blinking question mark prompts the user when it is time to make a response. Thus many of the factors that might cause interference on a paper and pencil version are eliminated, and the student can focus on the specific spelling task at hand.

Spelling Bee Games can be used by teachers to promote generalization of knowledge. When choosing word lists, teachers can choose those that correspond directly to what is being taught in class. If students are taught certain common spelling patterns via traditional classroom instruction, they will be able to apply what they have learned to a new set of words when they play Spelling Bee Games on the computer.

There is also the potential for transfer of skills. In all four games, students are provided with pictorial clues about the word they are to spell. Away from the computer, teachers could encourage students to visualize the picture of the word they are being asked to spell.

There are several ways in which the program could conform more closely to the tentative principles for effective instruction we have identified. For example, a useful addition would be the automatic advancement of students who demonstrate mastery at any level. This would maintain an appropriate level of challenge in addition to saving the teacher time. More corrective feedback could be provided. When a student makes a mistake, the mistake is not accepted. The player knows he or she is wrong, but does not know why. Teachers report that for some students this causes frustration. After a specified number of trials it would be helpful to show the correct spelling. Children may simply not be recognizing a picture, and therefore may be trying to spell the wrong word. In the games where the letters needed to spell the word are on the screen, children could use deductive reasoning skills to figure out the correct spelling, but this is not the case in all of the games.

There is practice in eye-hand coordination in two of the games. This has its advantages and disadvantages. For some children, having to manipulate letters on the screen helps to hold their attention and keep them actively involved in the activities. For others it can be frustrating to know where the letters belong, but not have enough fine motor control to get them in the correct place. A solution might be to make keyboard input an option.

In general, however, both MasterType and Spelling Bee Games incorporate features which have been identified as characteristic of instruction with appropriate targets, methods and uses of computer technology. The commercial success of this software suggests that those features we have identified as important for effective instructional software are the same features the learner responds favorably to, leading, in turn, to consumer purchases. The marketplace, in this sense, supports our analysis, yet much more empirically derived evidence to support these considerations in the design of software for the learning disabled is needed, and can only come with more systematic examination.

IV. IMPLICATIONS FOR RESEARCH ON THE DESIGN OF COMPUTER-BASED INSTRUCTION

We have identified two promising targets for computer-based instruction of the learning disabled: (1) inefficient perceptual (enabling) skills that lead to excessive processing demands that, in turn, constrain effective cognitive performance, and (2) higher-level cognitive processing skills that can provide learners with the ability to improve their own management of cognitive tasks. CREATE will explore both of these areas.

A key design objective for both enabling skill and processing skill oriented programs is to make them intrinsically motivating, that is, challenging, and appealing to visual and cognitive curiosity and to fantasy. An extremely important question remains, however. To what extent do design features that make software intrinsically motivating detract from the instructional quality of the materals in some other way? For example, from an instructional psychology perspective, clear performance models are critical for learners' easy acquisition of new skills and knowledge. Yet, graphic techniques that are necessary to appeal to the sense of learners' fantasy may distract from the clarity of the presentation.

If conflicts between design elements of this sort are encountered, what is the best compromise? Similar questions of compromise arise when tradeoffs are necessitated by the limitations of microcomputer systems. Both complex graphics techniques and complex self-adjusting instruction require substantial amounts of computer memory and use of valuable program execution time. This means that the more graphically sophisticated and adaptive a program is, the less room it leaves in the computer's memory for the substance of instruction and, typically, the more slowly it will operate. The best mix of graphic appeal, self-adjusting features, and extent of instruction available should be empirically determined.

The issue of how to design a program that will be most effectively adjusted to learner needs is an important one. A powerful general approach would be to present a game-like quiz at the outset of the learner's work with the program. On the basis of the learner's responses to a carefully balanced range of stimuli, the program would determine which skill or set of learner skills seems weakest. The program would then focus on this skill, adjusting difficulty levels upward as the learner showed improvement.

But is the complexity of this approach too costly in terms of available computer memory? A more pragmatic approach might be to have an assessment game separate from the remediation games, and then let the teacher intervene to monitor the assessment process, and select an appropriate game diskette. Or would it be better for learner morale and self-confidence to permit the learner to make selection decisions or pre-set the difficulty levels in the instructional program?

Finally, to what extent should specialized peripheral equipment be used, taking both its cost and quality into account? Speech synthesis and recognition are now appearing in commercially-available software. Yet the quality of synthesized speech is far from the quality of human speech. Similarly, although at the frontier of technology development much effort is being invested in speech recognition, existing devices are still expensive and limited in capability. Can these speech oriented devices improve the effectiveness of some types of programs? Should prototypes be developed that use such peripherals, even though they are not widely available?

These and many of the other questions raised in this paper can best be answered through systematic experimentation and evaluation. CREATE staff will begin development of prototypes focusing on the devlopment of enabling skills associated with high reading ability during the spring of 1984. The focus on enabling skills will continue through the fall of 1985 when CREATE staff will turn to the development of processing-skill-related prototypes. The Cupertino and Fremont School Districts in Santa Clara County, California, will provide laboratory sites for the trial of prototype software and will represent the expert viewpoints of practitioners regarding ideas for prototypes and the sharing of opinions about their strengths and weaknesses when completed.

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