Instructional Science 21: 427–449 (1993)

Instructional conditions for using dynamic visual displays: a review

OK-CHOON PARK & REGINALD HOPKINS
U. S. Army Research Institute, 5001 Eisenhower Avenue, Alexandria, VA 22333, U.S.A.

Abstract. A review of research related to the learning effect of dynamic versus static visual displays in media-based instruction is presented. The analysis reveals that the dynamic visual display (DVD) is generally more effective than the static visual display (SVD). However, the research findings do not consistently support the superior effect of DVDs. These conflicting findings seem to be related to the different theoretical rationales and methodological approaches used in various studies and suggest that the use of DVDs should be determined selectively. From the literature review and theoretical discussions about instructional functions of DVDs, we propose six instructional conditions under which DVDs can be effectively used. The conditions are for: (a) demonstrating sequential actions in a procedural task; (b) simulating causal models of complex system behaviors; (c) explicitly representing invisible system functions and behaviors; (d) illustrating a task which is difficult to describe verbally; (e) providing a visual analogy for an abstract and symbolic concept, and (f) obtaining attention focused on specific tasks or presentation displays. Finally, several important considerations for the design and presentation of DVDs are discussed.

Introduction

Due to the computer's capability to control multimedia information, including animation and interactive video, the dynamic visual display has become a primary component of media-based instruction. The purpose of this paper is to provide research-based guidelines for applying dynamic visual displays in media-based instruction.

The dynamic visual display (DVD) is defined as the presentation of any type of pictorial and graphical movement during instruction. Movement may range from continuous motion as in films, television, and interactive video discs to graphical animations in computer-based instruction (CBI), such as simulations of chemical processes, electronic behaviors, and pop-in arrows, labels, etc. The DVD, regardless of whether it is film or computer-based graphic animation, consists of a series of still pictures, with slight changes from one to the next, of the object(s) which will appear to move. The human visual system perceives motion when there is actually no physical movement by combining the discrete information into a smooth, continuous event. Thus, the perception of motion seems to depend primarily upon a person's mental model to expect motion (Norman, 1982). The term 'dynamic visual display' (or DVD) in this paper refers to instructional presentations that involve the manipulation of stimuli that is uncharacteristic of still or static presentations. Presentations characterized by no movement or object manipulation are defined as still or static.

To derive research-based guidelines on the use of DVDs, we first reviewed literature on the learning effect of DVDs and then attempted to identify their important instructional roles. Finally, we propose specific conditions under which DVDs can be effectively used.

Before reviewing the empirical studies, we describe two psychological paradigms (behavioristic and cognitive) that may have provided theoretical justifications for the use of DVDs in the design of most of the studies. We think the psychological paradigms are important not only to examine the theoretical bases used for the study, but also to derive the instructional roles of DVDs and instructional conditions under which DVDs can be effectively used.

Psychological paradigms

Research on the instructional roles of visual displays evolved out of two distinctive paradigms of learning theory: (a) a behavioristic paradigm which places primary emphasis on principles of associative and perceptual learning, and construction of learning conditions, using visual displays, eliciting necessary responses required in the task (Guthrie, 1935; Skinner, 1963; Thorndike, 1913); and (b) a cognitive paradigm that concerns cognitive structures and processes for explaining the network of verbal and visual representations (e.g., Clark and Paivio, 1991; Paivio, 1971, 1986). Neurophysiological studies for understanding the perceptual process of visual stimuli are not of concern in this review because their direct implications for instruction are limited.

Behavioristic paradigm

The behavioristic paradigm was used as the theoretical basis for most of the early research on visual displays in instruction. Within this paradigm, it is assumed that learning requires only association by contiguity and that most associations are mediated by perceptual and/or verbal responses (Thorndike, 1913; Guthrie, 1935; Skinner, 1954). Since many of the early researchers in the field conceptualized learning as the acquisition of new response capabilities, instruction focused on the development of responses that were not elicitable by a stimulus condition or situation existing prior to learning. Thus, visual-form was employed as a stimulus for facilitating the acquisition of new stimulus-response contingencies (May, 1958).

The functional significance of the visual variable was threefold: 1) it served as a cue for guiding and directing attention; 2) once attention has been obtained, it is assumed that an association between the narrated and visual components would cue the learner to the importance or significance of those portions of the instruction, and, thereby, elicit implicit (verbal or perceptual) responses to it; and 3) these verbal and perceptual responses would serve as cues in performance on an unprompted or terminal application (Lumsdaine,1961; May and Lumsdaine, 1958; Sheffield, 1961). In this paradigm, instruction is conceptualized as the 'management of stimulus-response contingencies', and dynamic features of the visual displays (i.e., motion) provide an additional tool for controlling the stimulus conditions that foster or regulate the occurrence of appropriate responses – responses that should lead to the acquisition of new behaviors, skills, etc.

Cognitive paradigm

Since Wundt (1912) claimed that all thought processes were accompanied by images, numerous studies have been conducted to understand the visual thought process or visual cognition (see Kosslyn, 1980) and to investigate the learning effect of images (e.g., Lesgold, Levin, Shimron and Gutterman, 1975; Lesogold, McCormick and Gollinkoff, 1975; Levie and Lentz, 1982; Levin, Anglin and Carney, 1987; Levin and Lesgold, 1978; Pressley, 1976, 1977).

A psychological paradigm for understanding the structures and processes of mental imagery is presented in the percept-analogy theory. In this theory, the general view of imagery is that mental images in essence are percepts that arise from memory rather than from ongoing sensory stimulation (Kosslyn, 1980).

According to Paivio's dual-coding theory (1971), information in memory is represented by two types of codes: image and verbal. Although there is controversy over the distinction between verbal (propositional) and nonverbal (pictorial) codes in memory (see Kosslyn, 1980; Johnson-Laird, 1983), the structural relationships and functional processes of the two different memory codes presented in the dual-coding theory provide clear theoretical implications for using visual displays in instruction. Thus, in this paper, Pavio's dual-coding theory is discussed as the representative paradigm of cognitive learning theory.

Pavio (1971, 1986) argues that human cognition is specialized for dealing with language and with nonverbal objects and events. The language system deals directly with linguistic input and output, while at the same time serving a symbolic function with respect to nonverbal objects, events, and behaviors. The nonverbal system deals with modality-specific images for shapes, environmental sounds, actions, skeletal or visceral sensations related to emotion, and other nonlinguistic objects and events. Such imaginal representations are analogous or perceptually similar to the events that they denote. Nonverbal representations can encode information simultaneously or in parallel, in contrast to verbal representations which encode sequentially.

The verbal and nonverbal representations are linked into a complex associative network. Links between the two subsystems, called 'referential connections', join corresponding verbal and imaginal codes and potentially allow such operations as imaging to words and naming to pictures. Representations within the verbal or nonverbal systems are joined by a second kind of link, called 'associative connections'. Words are joined to other related words and images to other images in either the same or different sensory modalities (Paivio, 1971, 1986; Clark and Paivio, 1991). These connections explain the complementary functions of one representation to the activation of another in a different or the same subsystem. Particularly, the referential connections suggest that if something is coded into both forms, verbal and imagery, it is more likely to be remembered because representation of one form can activate the other.

Dynamic features of visual displays bring three attributes to an instructional setting: visualization, motion and trajectory of an object (Klein, 1987). Thus, DVDs provide a convenient means of visually representing imaginable events, actions, and ideas which change over time. They can make complex cognitive tasks more concrete and easy to understand by providing motion and trajectory attributes. Representing concepts and tasks involving motion with animation triggers the student's automatic ability of the visual system to induce apparent motion and directly encode them into the imaginal subsystem of memory, while static representation requires the student's ability and effort to form mental images of the task's dynamic nature by connecting and integrating discretely presented information (Reiber and Kini, 1991).

If the concepts and tasks are encoded in both verbal and visual forms, they will be retained in memory longer and will be more easily accessible than when they are encoded in a single form because the two subsystems in memory complement each other in the activation, representation, and development of related information or concepts. A study by Mayer and Anderson (1991) suggests that animated visual depiction and verbal explanation of a task should be presented simultaneously to facilitate the referential connections between visual and verbal representations.

Review of empirical findings

In this section, we summarize the major research findings on the instructional effectiveness of DVDs and SVDs. For most of the early research on visual displays, films and televisions were used as the instructional delivery mechanism. Because of the technological improvement of computers to handle sophisticated visual displays (including animation, interactive video), however, many recent studies on visual displays have been conducted in CBI. Although each medium as an instructional delivery system has different attributes to manipulate the characteristics of visual displays, we think the basic functions of visual displays remain the same in film/TV-based and computer-based instruction. Also, the use of film/TV-like visual presentations in media-based instruction has been rapidly increasing because of the computer's capability to control multimedia information. However, the interactive characteristics of CBI and its capability to use instructional information (including visual displays) in adaptive manners for individually different students may influence the determination of the instructional effects of visual displays in CBI. Thus, we divided this review into two parts: effects of visual displays in film/TV-based instruction and CBI.

Effects of dynamic vs. static visual displays in film/TV-based instruction

Some of the earliest research on the instructional effects of DVDs are reviewed by Freeman (1924). The general conclusion from this review is that DVDs are more effective than SVDs, but should be used in conjunction with verbal instructions (Hollis, 1924, 1927; James, 1924; McClusky and McClusky, 1924).

The work by Lumsdaine and associates (Lumsdaine, Sulzer and Kapstein, 1961; May and Lumsdaine, 1958) provides an extensive source of information about the early research on the effect of visual displays in instruction. In one study, Lumsdaine *et al.* (1961) examined the effects of DVDs versus SVDs in teaching 1,300 students (Air Force basic trainees) to read micrometer settings. The results of this investigation revealed that DVDs produced reliably more learning than SVDs, regardless of other instructional conditions and subject abilities.

In a study employing 3,314 Naval recruits, Roshal (1961) examined the effect of DVDs versus SVDs (and other instructional variables such as viewing angle, participation, etc.) on learning a procedural task (knot tying). DVDs were superior to SVDs. Roshal concluded that the accurate and continuous representation of the task procedures using DVDs should prove most effective in learning a procedural task.

In two studies, Spangenberg (1973) examined the effect of DVDs in teaching the disassembly of a M85 machine gun. A superiority for DVDs over SVDs was found. It took significantly less time and fewer sequencing errors for subjects under the DVD condition to perform the disassembly task.

In another study, Silverman (1958) investigated the effectiveness of DVDs on learning to load and dry-fire a 45-caliber pistol, an M2 carbine, and an M1 rifle. Subjects trained with DVDs outperformed subjects trained with SVDs. Silverman concluded that DVDs should be employed for training a task which is procedural in nature. The positive effect of DVDs was also reported by Goldstein, Chance, Hoisington, and Buescher (1982). Subjects who received pictorial content stimuli with DVDs were better than subjects who received them with SVDs on the pictorial short-term recognition test.

The interaction effect of DVDs with subject aptitude (spatial aptitude and mental ability) was reported by Blake (1977). He tested the effect of DVDs against those of SVDs and SVDs plus motion cues (i.e., arrows for indicating motion) in teaching the movement patterns of five chess pieces to 84 college students. In this study, subjects of high aptitude showed no differences between the three visual display conditions. However, subjects with low aptitude performed better with DVDs or SVDs plus motion cues than with SVDs alone. The difference between the DVD and the SVD plus motion cue conditions was not significant. Blake argued that the motion or motion cues (chess-piece movement or arrow) helped the low aptitude subjects in distinguishing the figures (i.e., chess pieces) from the ground (i.e., chess board).

Contrary to the above findings, several researchers found DVDs to be of little utility for instruction. For example, Laner (1954) compared the effects of DVDs and SVDs for teaching college students how to dismantle, repair, and reassemble a sash-cord window. The DVD of the procedure was not significantly more effective than the SVD. Under similar conditions, Laner (1955) examined the effect of DVDs on comprehension of a complex task. The DVD condition, again, was not significantly better than the SVD condition. He concluded that there appear to be no special effects attributable to DVDs over SVDs.

In another study, Swezey, Perez and Allen (1991) examined the effect of DVDs versus SVDs on learning and transfer of electro-mechanical troubleshooting skills by college students. Out of the 26 possible comparisons of the dependent variables measured, only three showed significant differences in favor of DVDs, while other comparisons showed no difference. Swezey *et al.* attributed the favorable comparisons to type 1 errors. They concluded that DVDs are not a requirement in training for predominantly cognitive troubleshooting tasks.

Effects of dynamic vs. static visual displays in CBI

To investigate the effects of DVDs and SVDs, Baek and Layne (1988) developed two CBI programs to teach the mathematical rule for calculating an average. They found that students in the DVD group outperformed those in the SVD group. These results were consistent with findings by Rigney and Lutz (1976) and Alesandrini and Rigney (1981) that animation was more effective than plain text in teaching various chemistry concepts in CBI.

McCloskey and Kohl (1983) conducted a series of studies to investigate whether the presentation of DVDs influences students' naive (incorrect) beliefs about the behavior of moving objects. They provided subjects with DVDs and SVDs of a ball on a string, and asked them to indicate the path the ball would follow if the string broke. They found that the DVDs did not significantly change or improve subjects' naive beliefs.

In a similar study, Kaiser, Proffitt and Anderson (1985) examined the effects of DVDs (animated motion) in selecting the correct natural trajectory path of a ball. Results indicate that both adults and children in the DVD condition chose the correct path more often than their counterparts in the SVD condition. Kaiser *et al.* argued that the significant contribution of DVDs, which was not consistent with the

McCloskey and Kohl's (1983) study, was demonstrated in their study because the dynamic (i.e., motion) presentation was more natural and far more accessible to the observers than in McCloskey and Kohl's (1983) study.

Reed (1985) conducted a series of experiments on the effectiveness of DVDs versus SVDs in improving students' estimates for algebra word problems (e.g., average speed, mixtures of different concentrations). Students were provided various computer simulated problems without verbal instructions on the correct procedures and asked to estimate the amount of time the computer would take to complete each task/problem. The results indicated that the use of DVDs was not reliably different from that of static displays. Thus, Reed concluded that DVDs are of no special benefit for instruction.

Caraballo-Rios (1985) investigated the effect of animation by comparing it to those of the text only and text plus SVD conditions in teaching college students concepts and rules required to compute the area of plane polygonal regions. The three conditions did not differ significantly from one another. Caraballo (1985) reported similar results after comparing the effects of the text only, text plus SVDs and text plus animation conditions in teaching physiological facts and concepts of the human heart to college students. King (1975)'s study also showed no significant effect of animation over SVDs in teaching mathematical concepts of the sine-ratio to Navy trainees.

Similar results were found by Rieber and Hannafin (1988). They employed three different orienting conditions (textual, animation, and textual plus animation) crossed with various levels of practice in teaching a group of fourth and fifth graders Newton's laws of motion. There were no significant differences found between the orienting conditions. The non-significant effect of DVDs (animation) over SVDs was found again in another study by Reiber (1989). Basically the same results were reported by Peters and Daiker (1982) and Moore, Nawrocki and Simutis (1979).

However, under similar conditions for teaching 4th graders Newton's Laws, Rieber, Boyce and Assad (1990) found animation to be a significant factor in facilitating the encoding and retrieval of information. Subjects in the animation condition took significantly less time to complete post-test measures than did subjects in either the static graphics or no graphics condition.

In two other studies, Reiber (1990a) investigated the effects of animation using the same materials (i.e., Newton's Laws) to teach similar subjects (4th graders). In one study, he found that animation promoted learning significantly more than static graphics or no graphics condition when behavioral practice (i.e., multiple-choice questions after the lesson) rather than cognitive practice (i.e., structured simulation activity) was accompanied. The author concluded from the results of this study that animation is effective only under certain conditions. However, it is difficult to understand why animation is effective when it accompanies a non-animational multiple-choice type of practice and not effective when accompanying an animated simulation activity type of practice. If practice is a part of instruction, the effects of animation seemed to be contradictory within the instruction. The effect of animation was more clearly demonstrated in the other study (Reiber, 1991) in which the same materials were taught to similar subjects. Animation was more effective not only for teaching intentional learning objectives, but also for facilitating incidental learning.

The study by Collins, Adams and Pew (1978) showed the instructional value of animation as a means for obtaining focused attention to specific parts of displays. They compared the effect of an interactive map display against those of a static labeled and unlabeled map displays in the process of evaluating the SCHOLAR, an intelligent computer-assisted instructional system developed to teach the geography of South America. The interactive map display, which was presented with blinking dots indicating the city boundaries, was significantly more effective than either of the other displays.

Recently, Carpenter and Just (1992) found the limited effect of DVDs (animation) in teaching the basic structure and functions of a mechanical system to college students. Animation improved the performance of the subjects with low prior knowledge in answering questions about the motion of components that were presented with text (verbal explanations). However, animation was not helpful when presented without verbal explanations. Also, the effect of animation was local because it did not improve the subjects' overall understanding of the system structure and functions. Carpenter and Just argued that the subjects with low knowledge were primarily text-dependent and animation did not provide a general abstract schema for constructing a good mental model of the device. According to this study, subjects with high prior knowledge and abilities do not need verbal explanations and animation because they can make inferences from SVDs and form workable mental models.

Inconsistency in research findings

As observed in the above review, research findings on the effect of DVDs are not consistent. Some studies showed that DVDs are more effective than SVDs, while no significant effect of DVDs is not uncommon, particularly among more recent studies. We think the most significant factor accounting for these disparate findings lies in the researchers' conceptual approaches to learning and strategic applications of the unique features of DVDs.

The psychological paradigm and research results

The behavioristic paradigm dominated early research in visual displays (mostly for film or TV-based instruction). However, it does not appear to have extended to the recent work conducted after the mid 1970s because most researchers' psychological perspectives have shifted from behaviorism to cognitive psychology since the early 1960s. Thus, the cognitive paradigm has apparently been used as the theoretical basis for most recent studies on visual displays. However, many recent studies reviewed in this paper failed to show reliable differences of the instructional effect between DVDs and SVDs (see Table 1 for summary). Consequently, some researchers have concluded that DVDs (including animation and motion pictures) are of little utility for instruction, particularly for media-based instruction (e.g., Moore and Nawrocki, 1978; Reed, 1985).

In the behavioristic paradigm, as noted earlier, instruction was conceptualized as the management of learning. Hence, researchers focused on creating ideal learning conditions through the use of different types of visual displays. Motion was used as a stimulus to elicit certain perceptual or verbal responses and thereby facilitate learning. Under this paradigm, many researchers have found that DVDs are superior to SVDs (Lumsdaine, 1958b; Lumsdaine, Sulzer and Kopstein, 1961; May, 1958; Silverman, 1958; Spangenberg, 1973). This superiority is generally maintained for procedural tasks requiring a series of motional actions (Roshal, 1961) as well as cognitive tasks requiring conceptual understanding (Lumsdaine, Sulzer and Kopstein, 1961; May and Lumsdaine, 1958). It is presumed that such an effect is obtained because the saliency of DVDs, which cannot be explicitly manifested via SVDs, and the associated narration foster a mental set which leads to mental rehearsing or processing (mediated by language) of the contingencies of the stimuli and the resultant responses required for the task.

On the other hand, in many of the recent studies, the theoretical justifications and methodological approaches for the application of visual displays seemed to be loosely defined mainly because cognitive psychological paradigms did not provide specific guidelines for using visual displays. In this review, we found that some recent studies were conducted without even clear theoretical or logical justification for employing different types of visual displays and failed to show the specific use of visual displays. These researchers seemed to have been preoccupied with the general or absolute effect of DVDs. Having considered that the unique features of different types of visual displays were not selectively applied, it was not surprising that these studies could not demonstrate the specific instructional value of DVDs (Clark, 1983).

However, several recent studies, in which dynamic features of visual displays were employed for specific purposes on the basis of the cognitive psychological paradigm (e.g., Kaiser, Proffitt and Anderson, 1985; Reiber, 1991), clearly demonstrated the superiority of DVDs over SVDs. This suggests that the

Table 1. A research summary of effects of dynamic versus static visual displays

Author & Year	Delivery medium	Psychological paradigm	Type of task taught	Instructional condition DVD used for	Significance of effect
Blake, 1977	Film/TV	Behavioristic	Cognitive skill (Movement rules of chess pieces)	1,4,6	For DVD partially
Goldstein et al., 1982	Film/TV	Cognitive	Short-term recognition (a series of pictorial stimuli)	6	For DVD
Laner, 1954, 1955	Film/TV	Behavioristic	Procedural Skill (Repairing sash-window)	1,6	No difference
Lumsdaine *et al.*, 1961	Film/TV	Behavioristic	Cognitive Skill (Reading micro-meter settings)	1,2,4,6	For DVD
Roshal, 1961	Film/TV	Behavioristic	Procedural Skill (Knot tying)	1,6	For DVD
Spangenberg, 1973	Film/TV	Behavioristic	Procedural Skill (Disassembling machine gun)	1,6	For DVD
Silverman, 1958	Film/TV	Behavioristic	Procedural Skill (Load & dry-fire rifles)	1,6	For DVD
Swezey *et al.*, 1991	Film/TV	Not clear	Procedural Skill (Troubleshooting diesel engine)	1,4	No difference
Alesandrini & Rigney, 1981	CBI	Cognitive	Concept Learning (Chemistry concepts)	2,4	For DVD
Baek & Layne 1988	CBI	Not clear	Rule learning (Mathematical rule for averaging)	1,4	For DVD
Carpenter, & Just, 1992	CBI	Cognitive	Conceptual understanding (Mechnical systems)	2,3,5	For DVD partially
Caraballo, 1985	CBI	Not clear	Conceptual understanding (Function of human heart)	3, 4	No difference
Caraballo-Rios, 1985	CBI	Not clear	Concepts & rule learning (Compution of polygonal areas)	4	No difference

Table 1 (continued). A research summary of effects of dynamic versus static visual displays

Author & Year	Delivery medium	Psychological paradigm	Type of task taught	Instructional condition DVD used for	Significance of effect
Collins *et al.*, 1978	CBI	Cognitive	Fact memorization (geographic locations)	6	For DVD
Kaiser *et al.*, 1985	CBI	Cognitive	Conceptual understanding (Trajectory of moving object)	4,5	For DVD
King, 1975	CBI	Not clear	Mathematical concept (Sine-ratio)	4	No difference
McCloskey & Kohl, 1983	CBI	Cognitive	Conceptual understanding (Trajectory of moving object)	4,5	No difference
Moore *et al.*, 1979	CBI	Not clear	Conceptual understanding (Psycho-physiological ear function)	3,4	No difference
Peters & Daiker, 1982	CBI	Not clear	Concept Learning (Chemistry concepts)	2,4	No difference
Reed, 1985	CBI	Cognitive	Self assessment (Estimating time needed for math problem solving)	1,4	No difference
Reiber, 1989	CBI	Cognitive	Conceptual understanding (Newton's laws)	4,5	For DVD
Reiber, 1990	CBI	Cognitive	Conceptual understanding (Newton's laws)	4,5	No difference
Reiber *et al.*, 1990	CBI	Cognitive	Conceptual understanding (Newton's laws)	4,5	For DVD
Reiber & Hannafin, 1987	CBI	Cognitive	Conceptual understanding (Newton's laws)	4,5	No difference
Rigney & Lutz, 1976	CBI	Cognitive	Concept Learning (Chemistry concepts)	2,4	For DVD

psychological paradigm (behavioristic or cognitive) used in the study does not determine the overall instructional value of the DVD. However, the psychological paradigm leads the researcher to perceive the different instructional roles of visual displays and to use the dynamic features of visual displays for different purposes.

Lack of strategic applications

The above review suggests that the effectiveness of visual displays is subject to the strategic applications of the unique features of the displays for the given instructional situation. Of particular concern are conditions related to both the learner and the learning task (Reiber, 1990b).

Attention is a perennial feature of learning. In many of the studies in which the effect of DVDs was significant, motion in the visual display served as an attention device for focusing and directing stimuli, which, it was presumed, would elicit overt or covert responses from the learner. The resultant verbal or mental image would then serve as a cue in an unprompted, terminal application. After not finding a significant difference between the DVD and SVD conditions, Peters and Daiker (1982) attributed the insignificant result to the lack of focused attention by stating that the DVDs did not focus students' attention on the desired to-be-learned features.

In using motion for instruction, it cannot be presumed that all individuals will attend equally, if at all, to specific stimuli in the presentation. Which stimulus patterns an individual perceives or responds to depends on a variety of factors (e.g., experience, prior knowledge, saliency of stimuli, learner aptitude, etc.). Thus, the indiscriminate presentation of motion can inhibit learning by misleading the student's attentional focus or causing cognitive overload. Several studies employing different attention-focusing techniques support the plausibility of this argument (Lumsdaine, 1958a, 1961; May and Lumsdaine, 1958; McGuire, 1961). For example, McGuire (1961) investigated the effect of two different versions of a motion film on learning a pursuit-motor tracking task. One version of the film was the steady, incessant presentation and the other had slow motion. He found that students learned significantly more when the items were depicted in slow motion than shown at regular speed. These results suggest that the principles of association and perceptual contiguity may not lead to learning unless special care is taken. Thus, motion or animation should be employed to ensure that the learner responds to (and processes) the necessary connections and associations in the instructional process (see Lumsdaine, 1961; May and Lumsdaine, 1958). Particularly, novices in the target content area are not likely to know how to attend to relevant cures or details provided by animation (Carpenter and Just, 1992; Reiber, 1990b).

Some studies (e.g., May and Lumsdaine, 1958; Carpenter and Just, 1992) have shown that poor student performance frequently results from the lack of a clear explanation of the critical features in the visual display. For example, in studies by Peters and Daiker (1982) and Swezey *et al.* (1991), the critical features and motion segments were not explained or highlighted. Thus, we think that the lack of explanation was one of the contributors to some of the non-significant findings in the studies reviewed in this paper. Mayer and Anderson (1991) suggest that animation and verbal explanation should be presented simultaneously to optimally support the encoding of the two different types of information in memory and their referential connections in the cognitive representation.

Probably the most significant shortcoming for non-significant studies is the lack of integrated considerations of learner characteristics, learning requirements of task characteristics and attributes of the instructional medium for the use of specific visual displays. One important feature of most behavioristic paradigm-based studies we reviewed is a careful deployment of the dynamic feature in the visual display with one or more instructional variables. They were employed as parts of instructional strategies such as advanced warning, demonstration, and procedural guidance. The same cannot be said for many recent studies where no difference was found since they lacked specifications regarding strategic manipulations of the dynamic features. For example, in the study by Swezey *et al.* (1991), the dynamic presentation of the visual displays was selected as a global approach to the instruction rather than as micro strategies for manipulating specific features during the instructional process. Thus, we believe that the lack of strategic applications of the dynamic features of visual displays could have masked the effect of DVDs that might have been positively influenced if they had been adequately selected and designed.

Despite the theoretical and methodological problems of some investigations and the resultant contradictory findings, the majority of the findings support the superior instructional effect of DVDs over static displays. As is summarized in Table 1, 15 studies out of 27 demonstrated the superior effect of DVDs, while 12 studies found no significant differences.

Recommendations: instructional roles of dynamic visual displays and conditions for use

This paper reviews research on the effects of media-based instruction employing DVDs and SVDs. The majority of research conducted before 1970 found that DVDs are more effective than SVDs. In contrast, many experiments over the past two decades have found no such effect. Notwithstanding the theoretical and methodological discrepancies which tend to forge a gulf between these findings, many contemporary studies appear to have ignored earlier research in this area.

Probably the most profound discrepancy separating the research is theoretical in nature. One important difference between studies which found significant effects of

DVDs and studies which found no such effects is that the former were guided by theoretical rationales which derived the appropriate uses for dynamic and static features of visual displays and their presumed effect. Accordingly, the learner variables, the learning requirements in the task, and/or the medium characteristics were appropriately coordinated in most of the studies that found significant effects.

Specifications regarding the utilization of the visual displays also seem to differentiate this literature. In most of the significant studies, the dynamic features of visual displays were strategically employed for specific learning effects. The insufficient strategic applications of the unique features of visual displays could explain the contrary findings in the studies. Thus, it is important to develop systematic guidelines for the strategic applications of the unique features of visual displays.

Stategic applications of dynamic visual displays

After reviewing the characteristics of different media selection models, Reiser and Gagne (1982) discussed learner characteristics, instructional settings, and domain tasks as the primary factors that should be considered in the selection of media. Kozma (1991) described the cognitively relevant characteristics, symbol systems, and processing capabilities of different media, including books, television, computers, and multi-media, to discuss the potential effect of media characteristics on the structure, formation, and modification of mental models. However, very few practical implications for applying DVDs are provided in these papers. Reiser and Gagné's discussion about DVDs (or motion) as media characteristics was very superficial and Kozma's discussion was too abstract and speculative. Levie and Lentz (1982) provided more specific guidelines for using visual displays, but the guidelines were limited to still visuals (i.e., pictures and graphics) in text. Recently, Reiber (1990b) provided three recommendations for using animation in CBI on the basis of a review of research findings: (a) Animation should be incorporated only when the attributes are congruent to the learning task; (b) Evidence suggests that when learners are novices in the content area, they may not know how to attend to relevant cues or details provided by animation; (c) Animation's greatest contributions to CBI may lie in interactive graphic applications (e.g., interactive dynamics). These recommendations provide general directions for determining whether and how animation should be used for a given instructional situation, but no specific guidelines for determining instructional conditions for applying DVDs.

Although the effect of DVDs was not tested against other types of visual displays, some recent studies (e.g., diSessa, 1982; Good, 1987; Mayer and Anderson, 1991; Reif, 1987) and intelligent tutoring systems (ITS) suggest how DVDs, including animation, could be effectively used. Based on studies reviewed in this paper, other studies cited above, and some ITSs, we describe several examples showing the strategic applications of the dynamic features in visual displays.

First, graphical animation has been effectively used to explicitly represent highly abstract and dynamic concepts in science, including time-dependent processes (diSessa, 1982; Kaiser *et al.*, 1985; Reiber, 1990a, 1991). Animation not only visually represents obvious observable processes, such as the motion of moving objects, but also allows the learner to represent his or her own progress in implementing intellectual processes (e.g., implementing the procedure specifying time-dependent or trajectory concepts). For example, diSessa (1982) used LOGO 'dynaturtle' to investigate strategies used by elementary school and college students in understanding the dynamics of Newton's laws. The students were required to represent Newton's laws (e.g., vector change in velocity) using the movement of the dynaturtle on the computer screen. White (1984) developed computer games using animation to help physics students understand Newton's laws of motion through actual manipulations of the object in the gaming process. Reif (1987) used animation to study the students' thought processes in learning the concept of 'acceleration'. The concept of acceleration was represented with motion of graphics and words. In addition, motion cues (e.g., arrows indicating directions) were presented to help the student's understanding.

Second, DVDs have been used as a visual analogy or cognitive anchor for the instruction of problem solving. For example, Lamb (1982) developed a computer game that allows students to compose music through animated visual experimentations of music pitches and melodic shapes. Reiser and his associates (Reiser, Beekelaar, Tyle and Merrill, 1991; Reiser, Ranney, Lovett and Kimberg, 1989) developed an ITS which can dynamically construct visual representations to guide the student's reasoning process in learning LISP. In the Geometry Tutor (Anderson, Boyle and Yost, 1985), dynamically constructed graphics are used to illustrate the proof process of geometric theorems. The progressive presentation of the visually structured proof process leads the student's reasoning process to connect the conclusion with the given premises by means of both backward and forward thinking paths.

Third, DVDs, particularly animation, have been used to simulate functional behaviors of mechanical or electronic systems and to demonstrate troubleshooting procedures (e.g., Woolf, Blegan, Jansen and Verloop, 1986; Hollan, Hutchins and Weitzman, 1983; Towne, Munroe, Pizzini and Surmon, 1987).

Fourth, graphical animation has been used to explicitly represent invisible flow of information or current in electronic systems (e.g., Newman, Gringneti, Gross and Massey, 1992; Park and Gittelman, in press).

Fifth, animation has been used as a substitute or aid for verbal communication. For example, Withrow (1978, 1979) used animation to teach language to aurally hanicapped children.

Although we limited our examination on the use of DVDs in CBI and ITS to the manipulation of specific components of instructional presentation, visual displays have been used as a primary means to create a total learning environment in which the student acquires various learning experiences through exploration of the simulated world. The creation of this 'microworld' (Papert, 1972, 1980) requires not only a non-conventional philosophy of education, but also innovative pedagogical ideas and technical expertise. Thus, it is beyond the scope of this paper to discuss how to use different types of visual displays in the development of microworlds, although we think that many implications discussed in this paper could be applied in the microworld environment as well.

Instructional roles of dynamic visual displays

From the review of research findings about the effects of DVDs, theoretical discussions for the use of DVDs, and their actual uses in ITS and traditional CBI, we have attempted to define specific instructional conditions under which DVDs can be effectively used. To provide theoretical justifications for the instructional conditions, we first identified important instructional roles of DVDs as follows:

1) As an attention guide. The salient features (i.e., motion) of DVDs can serve as a special stimulus to guide and direct the student's attention. For example, in a complex system, motion can be used to highlight critical features and their relation(s) to other components that might not be easily grasped or attended.
2) As an aid for illustration. Visual displays can be used to illustrate structural, functional or procedural relationships among components in a specific domain. For example, dynamic features of visual displays can be helpful in explaining sequential relationships of procedural actions in electronic troubleshooting. In this case, they are used as an aid for communicating the domain knowledge rather than for representing the knowledge itself.
3) As a representation of domain knowledge. DVDs are necessary to effectively represent certain domain knowledge which include movement and action. For example, if the functional behavior of a system is a main target for instruction, DVDs might be the most direct way to represent the knowledge.
4) As a device model for forming a mental image. Visual displays, particularly graphical animations, are useful to represent system structures and functions which are not directly observable (e.g., electricity flow). The graphical representation of invisible system functions or behaviors is particularly important to help the student form a mental model (Gentner and Stevens, 1983; Johnson-Laird, 1983) about the system, which may be difficult with verbal explanations or SVDs, either in isolation or in combination.
5) As a visual analogy or reasoning anchor for understanding abstract and symbolic concepts or processes. Abstract and symbolic concepts (e.g., velocity) become concrete and directly observable when they are represented

with computer-controlled animation. This kind of visual representation could serve as a reasoning anchor for understanding the past event or predicting the future event in a time-dependent trajectory process.

Instructional conditions for using dynamic visual displays

DVDs can be most effectively applied when both the characteristics of the domain knowledge and the characteristics of the students require one or more of the instructional roles described above. The following are six instructional conditions for which we recommend considering DVDs:

1) For demonstrating sequential actions in a procedural task. For example, the actual procedures for operating or repairing equipment can be clearly demonstrated through DVDs. The static presentation cannot show the actual motions involved in the procedures. The live demonstration of the procedures is not usually cost-effective because of the limited availability of experts and actual equipment.
2) For simulating causal models of complex system behaviors. For example, actual movements of various gauges in an airplane cockpit can be displayed through dynamic visual presentations to teach the causal relationships among the components. Although the actual systems can be used for the instruction, graphical simulations are usually preferable for at least the early stage of instruction. The use of an actual system is expensive and risky, the addition of instructional features (e.g., control of system speed) to the actual system is very difficult, and the structure and behaviors of the actual system are often too complex and sophisticated for the novice to understand.
3) For visually manifesting invisible system functions and behaviors. For example, electronic system behaviors or blood flow in the human body can not be directly observed. However, observation of the invisible process is important to understand the system's functions and behaviors and to form mental models about the system. Graphical animation can be effectively used to explicitly represent the invisible system functions and behaviors.
4) For illustrating a task difficult to describe verbally. For example, sophisticated relational reactions occurring simultaneously among many different components in a complex system or among chemical materials are very difficult to explain verbally because verbal information is processed only sequentially. DVDs can be very helpful for explicitly representing and illustrating the reactions or processes and for facilitating the formation of mental models about the processes, because visual information is processed (i.e., decoded and encoded) simultaneously or in a parallel fashion. Also, DVDs can be effectively used when students are not able to verbally

communicate because of their lack of knowledge in the task (e.g., foreign language learning) or limited mental or physical capacity (e.g., deaf students).

5) For providing a visually motional cue, analogy or guidance. For example, physics concepts involving a time-dependent process or trajectory can be represented concretely with graphical animation. DVDs will be helpful for the student to qualitatively understand the symbolic concept and form mental models about the concept. The mental models would allow the student to represent the phenomenon beyond the graphical presentation (i.e., predicting the future event or retrospecting the past event representing the concept). A visual analogy or guidance may also be used effectively to facilitate the thinking process in problem solving.

6) For obtaining attention focused on specific tasks or presentation displays. For example, specific relational movements among many different gauges in an airplane cockpit can be highlighted to focus the student's attention by animating only relevant features of a visual display. The selective demonstration and control of a system's features and behaviors are practically impossible in the use of an actual system.

Although we have described six instructional conditions appropriate for the use of DVDs, it should be noted that an essential requirement in all of the conditions above is that at the very minimum motion should highlight content and processes that are indispensable to learning. If DVDs are selected to provide specific instructional roles in a given condition, special consideration should be given to the display design and presentation. The visual displays should be systematically integrated with the characteristics of the domain contents and other instructional strategies. Following are some important considerations for the design and presentation of DVDs:

First, verbal explanation of the dynamic features in the display. The visual displays, particularly the dynamic features, should be presented with sufficient verbal explanation (May and Lumsdaine, 1958; Carpenter and Just, 1992). If the dynamic features are an essential component of the to-be-learned task, either an inadequate explanation or no explanation could result in the desired connections either not being processed or processed incompletely (see the cognitive paradigm for research in visual learning). Also, the student's attention on the to-be-learned features is mainly guided through verbal explanations.

Second, fidelity level of visual displays and animation. Concerning media-based instruction, care must be taken to avoid threats to validity. For example, too low fidelity (as might occur in slow motion displays and caricatural displays of computer graphics) may lead to spurious conclusions regarding the effectiveness of motion; in actuality, the poor performance could have been due to the low fidelity between the treatment implementation and the criterion task. This does not mean that the fidelity level should always be high. Some tasks are too complex to understand or too fast to visually perceive if they are presented with the actual fidelity in the displays. Thus, the fidelity level should be determined on the basis of the task characteristics and the intended instructional functions of the displays.

Third, student ability to perceive and understand visual information. The primary concern here is with the complexity and presentation speed of both displays and instruction. The instructional developer must be cognizant of the amount of information that the target students can process in a given time frame. For example, if the DVD is highly complex and presented with a high speed, it might be helpful for high ability students, but not low ability students. The limited effect of DVDs only for low ability students, which was found by Blake (1977) and Carpenter and Just (1992), might have resulted from the relative simplicity of the DVD presentations for the high ability subjects.

The most fitting conclusion regarding the effect and usefulness of DVDs in media-based instruction was described by Freeman (1924). In a letter to his colleague regarding some misleading reports on motion-based instruction in schools, he stated: "The effectiveness of motion ... has undoubtedly been over estimated in comparison with slides, stereographs, still pictures, and demonstration. They were not as effective as many people claim them to be... [However,] motion pictures have a distinctive part to play". Freeman is correct in stating that motion is not effective under all conditions or for all tasks and that it has very definite roles to play in instructional media. The instructional roles of dynamic features of visual displays and the instructional conditions appropriate for their use, as we discussed in this paper, are an attempt to move us closer to a realization of Freeman's "distinctive part to play".

Note

Opinions expressed herein are those of the authors and do not express or imply the views of the U. S. Army Research Institute or the U. S. Department of Defense.

References

Alesandrini, K. L. and Rigney, J. W. (1981). Pictorial presentation and review strategies in science learning. *Journal of Research in Science Teaching, 18,* 465–474.

Anderson, J. R., Boyle, C. F. and Yost, G. (1985). The geometry tutor. Proceedings of the International Joint Conference on Artificial Intelligence, Los Angeles, 1–7.

Baek, Y. K. and Layne, B. H. (1988). Color, graphics and animation in a computer-assisted learning tutorial lesson. *Journal of Computer-Based Instruction, 15,* 131–135.

Blake, T. (1977). Motion in instructional media: some subject-display mode interactions. *Perceptual and Motor Skills, 44,* 975–985.

Caraballo, J. N. (1985). The effect of various display modes in computer-based instruction and language background upon achievement of selected educational objectives. Unpublished Doctoral dissertation. The Pennsylvania State University.

Caraballo-Rios, A. L. (1985). An experimental study to investigate the effect of computer animation on the understanding and retention of selected levels of learning outcomes. Unpublished Doctoral dissertation. The Pennsylvania State University.

Carpenter, P. A. and Just, M. A. (1992). Understanding mechanical systems through computer animation and kinematic imagery. (Report No. ONR92-1) Arlington, VA: Office of Naval Research.

Clark, J. M. and Paivio, A. (1991). Dual coding theory and education. *Educational Psychology Review, 3,* 149–210.

Clark, R. E. (1983). Reconsidering research on learning from media. *Review of Educational Research, 53,* 445–460.

Collins, A., Adams, M. and Pew, R. (1978). Effectiveness of an interactive map display in tutoring geography. *Journal of Educational Psychology, 70,* 1–7.

diSessa, A. A. (1982). Unlearning Aristotelian physics: a study of knowledge-based learning. *Cognitive Science, 6,* 37–75.

Freeman, F. N. (1924). *Visual education: a comparative study of motion picture and other methods of instruction.* Chicago: The University of Chicago Press.

Gentner, D. and Stevens, A. L. (1983). *Mental models.* Hillsdale, NJ: Lawrence Earlbaum Associates.

Goldstein, A. G., Chance, J. E., Hoisington, M. and Buescher, K. (1982). Recognition memory for pictures: dynamic versus static stimuli. *Bulletin of the Psychonomic Society, 20,* 37–40.

Good, R. (1987). Artificial intelligence and science education. *Journal of Research in Science Teaching, 24,* 325–342.

Guthrie, E. R. (1935). *The psychology of learning.* New York: Harper and Row.

Hollan, J. D., Hutchins, E. L. and Weitzman, L. (1983). STEAMER: an interactive inspectable simulation-based training system. *The AI Magazine, 2,* 15–27.

Hollis, A. P. (1924). The effectiveness of the film and demonstration in teaching cooking. In F. N. Freeman (Ed.), *Visual education: a comparative study of motion pictures and other methods of instruction.* Chicago: The University of Chicago Press.

Hollis, A. P. (1927). *Motion picture for instruction.* New York: The Century Company.

James, H. W. (1924). The relative effectiveness of six forms of lesson presentation. In F. N. Freeman (Ed.), Vis*ual education: a comparative study of motion picture and other methods of instruction.* Chicago: The University of Chicago Press.

Johnson-Laird, P. N. (1983). *Mental models.* Cambridge, MA: Harvard University Press.

Kaiser, M. K., Proffitt, D. R. and Anderson, K. (1985). Judgments of natural and anomalous trajectories in the presence and absence of motion. Journal of Experimental Psychology: *Learning, Memory and Cognition, 11,* 795–803.

King, W. A. (1975). A comparison of three combinations of text and graphics for concept learning. (Report No. NPRDC-TR-76-16). San Diego, CA: Navy Personnel Research and Development Center. (ERIC Document Service No. ED112936)

Klein, D. (1987). Conditions affecting the effectiveness of animated and non-animated displays in computer-based instruction. Paper presented at the Annual Conference of the Association for the Development of Computer-Based Instructional Systems, Oakland, CA.

Kosslyn, S. M. (1980). *Image and mind.* Cambridge, MA: Harvard University Press.

Kozma, R. B. (1991). Learning with media. *Review of Educational Research, 61,* 179–211.

Lamb, M. (1982). Interactive graphical modeling game for teaching musical concepts. *Journal of Computer-Based Instruction, 9,* 59–63.

Laner, S. (1954). The impact of visual aid displays showing a manipulative task. *Quarterly Review of Experimental Psychology, 6,* 95–106.

Laner, S. (1955). Some factors influencing the effectiveness of a training film. *British Journal of Psychology, 46,* 280–294.

Lesgold, A., Levin, J., Shimron, J. and Gutterman, J. (1975). Pictures and young children's learning from oral prose. *Journal of Educational Psychology, 67,* 636–642.

Lesogold, A., McCormick, C. and Gollinkoff, R. (1975). Imagery training and children's prose learning. *Journal of Educational Psychology, 67,* 663–667.

Levie, W. and Lentz, R. (1982). Effects of text illustrations: a review of research. *Educational Communication and Technology Journal, 30,* 195–232.

Levin, J., Anglin, G. and Carney, R. (1987). On empirically validating functions of pictures in prose. In D. Willows and H. Houghton (Eds.), *The psychology of illustration, volume 2: instructional issues* (pp. 51–85). New York: Springer-Verlag.

Levin, J. and Lesgold, A. (1978). On pictures in prose. *Educational Communication and Technology Journal, 26,* 233–243.

Lumsdaine, A. A. (1958a). Attention directed to parts of a film. In M. A. May and A. A. Lumsdaine (Eds.), *Learning from films* (pp. 84–106). New Haven: Yale University Press.

Lumsdaine, A. A. (1958b). Cue and response function in pictures and words. In M. A. May and A. A. Lumsdaine (Eds.), *Learning from films* (pp. 123–149). New Haven: Yale University Press.

Lumsdaine, A. A. (1961). *Student response in programmed instruction.* Washington, DC: National Research Council.

Lumsdaine, A. A., Sulzer, R. L. and Kopstein, F. F. (1961). The effect of animation cues and repetition of examples on learning from an instructional film. In A. A. Lumsdaine (Ed.), *Student response in programmed instruction,* (pp. 241–269).Washington, DC: National Research Council.

May, M. A. (1958). Verbal responses to demonstration films. In M. A. May and A. A. Lumsdaine (Eds.), *Learning from films.* New Haven: Yale University Press.

May, M. A. and Lumsdaine, A. A. (1958). *Learning from films.* New Haven: Yale University Press.

Mayer, R. E. and Anderson, R. B. (1991). Animations need narrations: an experimental test of a dual-coding hypothesis. *Journal of Educational Psychology, 83,* 484–490.

McCloskey, M. and Kohl, D. (1983). Naive physics: the curvilinear impetus principle and its role in interactions with moving objects. *Journal of Experimental Psychology: Learning, Memory and Cognition, 9,* 146–156.

McClusky, F. D. and McClusky, H. Y. (1924). Comparison of six modes of presentation of subject matter. In F. N. Freeman (Ed.), *Visual education: a comparative study of motion pictures and other methods of instruction.* Chicago: The University of Chicago Press.

McGuire, W. J. (1955/1961). Some factors influencing the effectiveness of demonstrational films: repetition of instructions, slow motion, distributed showing and explanatory narration. In A. A. Lumsdaine (Ed.), *Student response in programmed instruction,* (pp. 187–207). **Place?**: National Research Council.

Moore, M. V. and Nawrocki, L. H. (1978). The educational effectiveness of graphic displays for computer assisted instruction. (Report No. ARI-TP 332) Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (NTIS No. AD AO62585).

Moore, M., Nawrocki, L. and Simutis, Z. (1979). The instructional effectiveness of three levels of graphics displays for computer-assisted instruction. (Report No. ARI-TP-359). Arlington, VA: Army Research Institute for the Behavioral and Social Sciences (ERIC Document Service No. ED 178–057).

Newman, D., Gringneti, M., Gross, M. and Massey, L. D. (1992). Intelligent conduct of fire trainer: intelligent technology applied to simulation-based training. In M. J. Farr and J. Psotka, *Intelligent instruction by computer: theory and practice* (pp. 239–250). Washington: Taylor and Francis, 239–250.

Norman, D. (1982). *Learning and memory.* San Francisco, CA: W. H. Freeman and Company.

Paivio, A. (1971). *Imagery and verbal processes.* Hillsdale, NJ: Holt, Rinehart and Winston.

Paivio, A. (1986). *Mental representations: a dual-coding approach.* New York: Oxford University Press.

Papert, S. (1972). Teaching children thinking. *Programmed Learning and Educational Technology, 9,* 245–255.

Papert, S. (1980). *Mindstorms: children, computers and powerful ideas.* New York: Basic Books.

Park, O. and Gittelman, S. (in press). Selective use of animation and feedback in computer-based instruction. *Journal of Educational Psychology. Educational Technology Research and Development, 40,* 27–38.

Peters, H. J. and Daiker, K. C. (1982). Graphics and animation as instructional tools: a case study. *Pipeline, 7,* 11–13.

Pressley, M. (1976). Mental imagery helps eight-year-olds remembers what they read. *Journal of Educational Psychology, 68,* 355–359.

Pressley, M. (1977). Imagery and children's learning: putting the picture in developmental perspective. *Review of Educational Research, 47,* 585–622.

Reed, S. K. (1985). Effects of computer graphics on improving estimates to algebra word problems. *Journal of Educational Psychology, 77,* 285–298.

Rieber, L. P. (1989). The effects of computer animated elaboration strategies and practice on factual and application learning in an elementary science lesson. *Journal of Educational Computing Research, 5,* 431–444.

Rieber, L. P. (1990a). Using computer animated graphics in science instruction with children. *Journal of Educational Psychology, 82,* 135–140.

Rieber, L. P. (1990b). Animation in computer-based instruction. *Educational Technology Research and Development, 38,* 77–86.

Rieber, L. P. (1991). Animation, incidental learning and continuing motivation. *Journal of Educational Psychology, 83,* 318–328.

Rieber, L. P., Boyce, M. J. and Assad, C. (1990). The effects of computer animation on adult learning and retrieval tasks. *Journal of Computer-Based Instruction, 17,* 46–52.

Rieber, L. P. and Hannafin, M. J. (1988). The effects of textual and animated orienting activities and practice on learning from computer-based instruction. *Computers in the Schools, 5,* 77–89.

Reiber, L. P. and Kini, A. S. (1991). Theoretical foundations of instructional applications computer-generated animated visuals. *Journal of Computer-Based Instruction, 18,* 83–88.

Reif, F. (1987). Instructional design, cognition and technology: applications to the teaching of scientific concepts. *Journal of Research in Science Teaching, 24,* 309–324.

Reiser, B. J., Beekelaar, R., Tyle, A. and Merrill, D. (1991). GIL: Scaffolding learning to program with reasoning-congruent representations. CSL Report 48, Princeton, NJ: Princeton University Cognitive Science Laboratory.

Reiser, R. A. and Gagné, R. M. (1982). Characteristics of media selection models. *Review of Educational Research, 52,* 499–512.

Reiser, B. J., Ranney, M., Lovett, M. C. and Kimberg, D. Y. (1989). Facilitating students' reasoning with causal explanations and visual representations. In D. Bierman, J. Breuker and J. Sanberg (Eds.), *Proceedings of the Fourth International Conference on Artificial Intelligence and Education.* Springfield, VA: IOS.

Rigney, J. W. and Lutz, K. A. (1976). Effects of graphic analogies of concepts in chemistry on learning and attitude. *Journal of Educational Psychology, 68,* 305–311.

Roshal, S. M. (1961). Film mediated learning with varying representations of the task: viewing angle, portrayal of demonstration, motion and student participation. In A. A. Lumsdaine (Ed.), *Student response in programmed instruction* (pp. 155–175). National Research Council.

Sheffield, F. D. (1961). Theoretical considerations in the learning of Complex Sequential tasks from demonstration and practice. In A. A. Lumsdaine (Ed.), *Student response in programmed instruction* (pp. 31–52). National Research Council.

Silverman, R. E. (1958). The comparative effectiveness of animated and static transparences. (Report No. NTDC-TR 78-1). Port Washington, NY: US Naval Training Device Center.

Skinner, B. F. (1954). The science of learning and the art of teaching. *Harvard Educational Review, 24,* 86–97.

Skinner, B. F. (1963). Operant behavior. *American Psychologist, 18,* 503–515.

Spangenberg, R. W. (1973). The motion variable in procedural learning. *Audio-Visual Communication Review, 21,* 419–436.

Swezey, R. W., Perez, R. S. and Allen, J. A. (1991). Effects of instructional strategy and motion presentation conditions on the acquisition and transfer of electro-mechanical trouble-shooting skill. *Human Factors, 33,* 309–323.

Thorndike, E. L. (1913). *Educational psychology, volume 2: the psychology of learning.* New York: Teachers College, Columbia University.

Towne, D. M., Munroe, A., Pizzini, Q. A. and Surmon, D. S. (1987). Representing system behaviors and expert behaviors for intelligent tutoring. Technical Report No. 108. Los Angeles: Behavioral Technology Laboratories, University of Southern California.

White, B. (1984). Designing computer games to help physics students understand Newton's laws of motion. *Cognition and Instruction, 1,* 69–108.

Withrow, M. (1978). Computer animation and language instruction. *American Annual of the Deaf, 123,* 723–725.

Withrow, M. (1979). Illustrating language through computer generated animation. *American Annual of the Deaf, 124,* 549–592.

Woolf, B., Blegan, D., Jansen, J. and Verloop, A. (1986). *Teaching a complex industrial process.* Philadelphia, PA: National Association of Artificial Intelligence.

Wundt, W. (1912). *An introduction to psychology.* London: G. Allen and Company.