

**A Review of the Fundamental Effects of Multimedia
Information Presentation on Learning**

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Abstract

This paper examines the question, "Does multimedia information presentation help people learn?" The paper begins by describing general learning theory and several specific theories more closely related to multimedia and learning. To determine whether general multimedia learning is effective, the paper reviews studies comparing learning in traditional classroom lectures to learning with computer-based multimedia. Using empirical studies, the paper identifies factors that appear to affect the ability to learn from multimedia information. Theoretical explanations for the factors are suggested. To provide applied benefits, the paper describes media allocation recommendations that are based on empirical findings. These recommendations support the overall finding that multimedia information presentation appears to help people learn in specific, carefully defined situations. (54 pages, 212 references)

Chapter 1 Introduction

The computer user interface is the means by which a person communicates with a computer and a computer communicates with a person. The typical user interface consists of displayed text, text entry fields, and graphical controls such as radio buttons to manipulate information. Peripheral control devices such as a keyboard and mouse are also usually included.

User interfaces have evolved in a gradual, somewhat predictable fashion. User interfaces have become less like machines and more like people. The original user interfaces were based on text. They consisted of a simple command line for entering commands and a display to show textual information. This type of interface is typified by older mainframe computers and by the more familiar Microsoft Disk Operating System (MS-DOS). The next generation of user interfaces was based on graphics. This kind of user interface employed windows, pull down menus, and other graphical controls to display and manipulate information. Examples of graphical user interfaces include Microsoft Windows, the Apple Macintosh, and Motif for UNIX.

It appears that the next style of user interface will typify to a greater degree the diverse ways people acquire and manipulate different kinds of information in their perceptual world. The next style of user interface will be based on multimedia. Multimedia uses text, graphics, animation, pictures, video, and sound to present information to the user. Examples of multimedia user interfaces include Microsoft's Encarta encyclopedia and NCSF MOSAIC for the Internet. The number of software products that employ multimedia user interfaces will likely increase rapidly for two reasons. First, people prefer multimedia user interfaces (Bosco, 1986; Bryant, Brown, Silberberg, & Elliot, 1980; Fletcher, 1989, 1990; Holliday, Brunner, & Donais, 1977; Rigney & Lutz, 1976; Samuels, Biesbrock, & Terry, 1974; Sewell & Moore, 1980). Second, the cost of multimedia enabled computers is decreasing rapidly into price ranges that are suitable for the commercial mass market. For example, very well equipped multimedia enabled machines are now available for less than \$2,000 (Calica, 1994). Prices are expected to continue to drop even as component value increases.

Multimedia user interfaces give the user interface designer a huge variety of modes in which to present information. Media can be used separately (e.g., verbal information presented textually), redundantly (e.g., verbal information presented textually and auditorally), or in combination (e.g., verbal information presented auditorally and pictorial information presented via video). Although many multimedia user interface design options exist, utilizing these media in an effective manner is a significant challenge to interface designers.

Two ways to examine the effectiveness of multimedia user interfaces are its:

- Ability to entertain
- Ability to instruct.

An entertaining multimedia user interface is one that captures the user's attention and encourages the user to continue interacting with the software application. Education is not usually an objective of these applications. Popular computer games such as *Myst* by Broderbund or *Outpost* by Sierra On-line are examples of multimedia user interfaces that are entertaining, but not necessarily educational. Another way to examine the effectiveness of a multimedia user interface is to determine how well it helps people learn. Multimedia user interfaces are employed increasingly for computer-based tutorials and other forms of on-line education. The costs of developing these applications can often be justified quite easily. For example, Andersen Consulting expects a \$10 million return on investment from a multimedia version of its Business Practices course and Pacific Bell believes its multimedia internal policies and procedures course will save about \$6 million (Jerram, 1994). Steelcase used self-paced multimedia to reduce the cost of training a student from about \$200 per year to \$20 per year (Rifkin, 1991). The objective of these kinds of applications is to help users acquire knowledge and skills, but not necessarily to entertain.

The field of computer-based multimedia user interface design for learning is in its infancy. The field is currently troubled by overhype and the absence of empirically based user interface design guidelines. In an effort to help move the field forward, this paper focuses on fundamental aspects of multimedia information presentation to aid human learning. The emphasis is on identifying theories and principles for presenting multimedia information effectively. This paper also tries to identify which media to use to help people learn specific information.

This paper begins by reviewing literature that describes general theories of human learning and several specific theories that are more closely related to learning from multimedia. This theoretical information establishes a foundation for understanding human learning and provides a way to make predictions regarding when and why multimedia helps people learn. The theories also may improve our ability to integrate and organize the results of studies examining multimedia and learning.

This paper then reviews the results of studies comparing classroom instruction to multimedia computer-based instruction. To be successful, multimedia instruction must be more effective than the current, standard form of instruction—classroom lecture. Otherwise, multimedia instruction is an inappropriate and unnecessary application of technology. If multimedia instruction appears to be superior to classroom instruction, then the next step is to try to determine why. This paper reviews a wide variety of empirical studies from psychology, education, and computer science to identify factors that appear to influence the ability to learn from multimedia. This paper also uses the earlier theoretical ideas to develop possible theoretical explanations for each factor.

To provide applied benefits, the paper uses the results of studies to derive empirically-based recommendations for selecting media to communicate specific kinds of information. Since many multimedia user interface design guidelines are based on judgment or experience (e.g., Allen, 1974; Arens, 1992; Arens, Miller, Shapiro, & Sondheimer, 1988; Elhadad, Seligmann, Feiner, & McKeown, 1989; Feiner & McKeown, 1990, 1991a, 1991b; Reiser & Gagne', 1982), the development of guidelines based on the results of a large number of empirical studies is a unique, practical contribution. The paper concludes with a summary of theoretical explanations for the results of multimedia learning studies and makes suggestions for several studies that may help to advance the field.

General Learning Theory

"Learning" is a very large field of study. The field is generally divided into behaviorist and cognitive viewpoints. The behaviorist theories of learning are known as classical and operant conditioning. In classical (Pavlovian) conditioning (cf. Pavlov, 1927/1960), the subject learns contingencies in the world. For example, to a dog, food can be considered an unconditioned stimulus and salivation an unconditioned response. If a bell is repeatedly paired with the unconditioned stimulus (the food), then the bell becomes a conditioned stimulus and the bell alone can produce the unconditioned response (salivation). In operant (instrumental or Skinnerian) conditioning (cf. Skinner, 1963), the subject learns contingencies between actions and outcomes. For example, when a pigeon pecks a button, a food pellet is dispensed. The food pellet is rewarding, the action is reinforced, the pigeon learns to associate the peck with the food, and the pigeon repeats the behavior. So, in the behaviorist view, learning is the association of stimuli and responses.

Although valuable for improving our knowledge about learning, the results of behaviorist work with animals were not always generalizable to humans (cf. Grice, 1948; Lorge & Thorndike, 1935; on the effect of delay of knowledge of results on motor performance). The behaviorist view of learning has gradually fallen from favor in instructional research (Park & Hopkins, 1993) and has been replaced with views more consistent with cognitive psychology.

In cognitive psychology, learning is thought of as the development and linking of a network of cognitive structures. These structures are concepts, procedures, facts and other kinds of information. New information is connected to prior information and therefore becomes easier to retrieve. This paper will focus on the cognitive psychology view of learning.

Learning can also be thought of as explicit or implicit. Explicit learning is conscious, controlled learning. For example, explicit learning occurs when a person is asked to learn a list of words and is later tested on the ability to recall the words. Implicit learning is less conscious, less controlled learning. For example, implicit learning occurs when a person is given a list of words without being asked to learn them, is asked to perform a word fragment task (e.g., supply the missing letters for s _ r _ w b _ _ y), and is later tested on the ability to recognize the words from the list (e.g., Roediger, 1980). Even though the words were not studied, the person tends to complete the word fragments using words from the list (e.g., strawberry), but performs poorly on the word recognition test. Although the word fragment test shows that the person unconsciously knows the words, the recognition test suggests that the person has no conscious memory of the words. This is implicit learning. Since explicit learning is a larger, easier-to-test component of our learned information, it will be emphasized in this paper.

To develop a foundation for examining the effects of multimedia on learning, this chapter begins by describing a broad, general theory of how people learn. The model, types of memory, and processes included in this theory also appear in the more specific theories described later in the chapter.

Sensory Store

For this paper, learning is "the act of deliberate study of a specific body of material, so that the material can be retrieved at will and used with skill" (Norman, 1982, p. 3). According to general human learning theory (for example, Norman, 1982), new knowledge is first received by a sensory store such as a briefly retained visual image (iconic memory) or auditory memory (echoic memory).

Short-term Memory

Information in the sensory store can be transferred to a low capacity, short-term working memory using top-down processing or bottom-up processing. Top-down processing, or conceptually guided processing, is controllable by the person, uses conscious resources, and proceeds down from the higher conceptual levels. Bottom-up processing, or data-driven processing, is more automatic, not as much under the person's control, and probably does not use conscious resources. Bottom-up processing proceeds from the sensory data, pulling out relevant features to create the information that the sensory data represent. Once in the working memory, information can be kept there by rehearsing it.

Working memory may not be a single storage area, but a set of storage systems that are coordinated by a "central executive." Baddeley (1983, 1988b) proposed separate systems for verbal and pictorial information. For example, auditory information such as speech is retained in verbal working memory called the articulatory loop system. This type of working memory helps people comprehend speech. Visual, spatial information such as images are retained in visual memory called the visuo-spatial sketch pad. This type of working memory helps people retain and manipulate visual information when performing tasks such as using recalled images to count the number of pictures on the walls of their apartments. The existence of separate, coordinated working memory systems is supported by a study (Logie, Zucco, & Baddeley, cited in Baddeley, 1988a) in which people performed two tasks simultaneously that involved working memory. For example, people were asked to perform a verbal memory span test (identify which letter in a list of letters changed between two successive list presentations) with a secondary verbal task (keep a running sum of numbers) or a secondary visual task (remember a visual array of letters). Performance was better with the secondary visual task. This result suggests that the secondary

verbal task interfered with the primary verbal task, possibly because both tasks involved the same verbal working memory. Similar results were obtained using a visual primary task.

Long-term Memory

To transfer information from the low capacity, short-term working memory to the high capacity, long-term memory, the person searches the long-term memory for connections to the information in short-term memory. These connections organize the new information from a large number of independent units into a smaller number of organized groups of units. A study by Bower, Clark, Lesgold, and Winzenz (1969) supports the idea that the organization of information affects memory. These researchers presented 28 items randomly or in organized categories (for example, rare metals, common metals). People had higher recall for the organized items than the unorganized items. Halpern (1986) obtained similar results when testing the recall of song titles organized by genre (for example, Christmas songs). Rabinowitz and Mandler (1983) found that students recalled more verb-noun phrases (e.g., "go to mountains") when the phrases were presented according to an organized story schema (e.g., "Going Skiing") than when the phrases were presented in an unorganized fashion taxonomically (e.g., "Places"). Similarly, Smith, Adams, and Schorr (1978) showed that the time it took people to recognize a fact as part of a memorized set increased as the number of unintegrated facts increased (e.g., "Marty was asked to address the crowd" does not integrate "Marty broke the bottle" and "Marty did not delay the trip"), but stayed constant as the number of integrated facts increased (e.g., "Marty was chosen to christen the ship" integrates "Marty broke the bottle" and "Marty did not delay the trip").

The process of moving information from the short-term memory to the long-term memory is called encoding. Encoding connects new knowledge to prior knowledge. This process can be improved when the person elaborates on the information (Anderson, 1980, 1983; Anderson & Reder, 1979). The person connects the information in short-term memory to information in long-term memory. For example, if a person needs to remember the paired associate "dog-chair," the person may elaborate on this information by connecting it to the long-term memory that his dog Fido sleeps on a favorite chair. Learning is improved because new information is linked with prior knowledge.

Studies by Stein and Bransford (1979) and Reder (1979) found that this elaborative processing improves recall. In the Stein and Bransford (1979) studies, college students read sentences with adjectives that were not elaborated (e.g., "The old man bought the paint," underlines added by the author) or sentences in which the second clause was an elaboration of the adjective in the first clause (e.g., "The old man bought the paint to color his cane," underlines added by the author). Using fill-in-the-blank sentences, the students recalled the adjective from the first clause (e.g., "old") better in the elaborated sentences than in the sentences that were not elaborated. When college students were prompted to generate closely related elaborations of the first clause (e.g., "Why might this man be engaged in this particular type of activity?") or less related elaborations of the first clause (e.g., "What else might happen in this context?"), recall was better for the sentences that received closely related elaborations. In the Reder (1979) study, adults read several short stories. Every few sentences, one group answered a true-false forced elaboration question about the previous sentence or two. Another group did not answer questions. At a 48-hour delay test, adults who had answered forced elaboration questions were quicker to answer true-false questions about the stories than adults who had not answered forced elaboration questions.

Encoding the same information differently appears to improve recall. Madigan (1969) gave college students two lists of 44 cue-target word pairs (e.g., speed—ENGINE) to learn. For one group of students, a target was repeated immediately with the same cue (e.g., ... speed—ENGINE, speed—ENGINE ...). For another group, a target was repeated immediately with a different cue (e.g., ... speed—ENGINE, valve—ENGINE ...). Free recall of the target words was higher with the different cues than with the same cues. The repeated target word may have been encoded differently by changing the cue word. It appears that differential encoding of the target word improved recall.

Another technique that is believed to improve the transfer of information from short-term memory to long-term memory is to manipulate the levels (or depth) of processing of the information (Craik & Lockhart, 1972). According to this approach, the way an item is processed affects memory for that item. Processing the physical characteristics of an item is thought to be "shallow," so memory for that item should be poor. Processing the meaning of an item is thought to be "deep," so memory for that item should be good. The levels of processing idea is supported by a study (Craik & Tulving, 1975) in which people were given a list of concrete nouns, then the people were asked to answer one of three types of questions about each noun: (1) what was the case of the word (e.g., uppercase or lowercase) (this question processes physical characteristics), (2) what is a rhyme for the word, and (3) does the word fit into a given sentence (this question processes the word's meaning). The researchers believed that the levels, or depth, of processing increased from question (1) through question (3). A recognition test found that learning improved as the "depth" of processing increased. However, this theory has been criticized (for example, Baddeley, 1978) because the inability to measure depth of processing results in a circular argument: items processed more deeply are remembered better; items remembered better are processed more deeply. Processing appears to be based on domains, such as semantic and phonemic, rather than on a continuum of levels. Also, the type of learning test used (e.g., semantic versus rhyming) appears to affect memory (cf. Morris, Bransford, & Franks, 1977).

By connecting information to prior knowledge, the information becomes interpretable and meaningful. Haviland and Clark (1974), for example, found that the time it took people to understand several sentences depended on whether the sentences were related or unrelated. The related sentences were understood more quickly. Bransford and Johnson (1972) wrote ambiguous paragraphs, then showed the paragraphs to high school and college students. The students remembered more information from the paragraphs when the paragraphs had a title that allowed the students to use prior knowledge to understand the ambiguous paragraphs (for example, "Washing Clothes") than when the paragraphs lacked a title. Spilich, Vesonder, Chiesi, and Voss (1979) found that people who had more prior baseball knowledge were better able to remember descriptions of baseball games than people with comparatively less baseball knowledge. For information not related to baseball, they found no differences in recall. On perception and memory tests involving chess pieces on a chessboard, Chase and Simon (1973) and Chi (1978) found that prior chess knowledge positively affected performance.

So, it is easier to learn new information if it can be put into an existing knowledge framework. New knowledge depends on old knowledge. According to Norman (1982, p. 12), "The more one knows, the easier it is to learn more." Prior knowledge helps people understand and remember information because new information can be: (1) made more meaningful, (2) incorporated into existing knowledge, and (3) retrieved with existing retrieval schemes. Multimedia information presentation can help people learn if it facilitates these processes.

Specific Learning Theories

Several specific theories are more closely related to multimedia and learning. These theories share features of the general learning theory summarized above, but can help explain learning in more narrowly defined situations. The specific learning theories are:

- Mayer's theory of explanative illustrations,
- Paivio's dual coding theory,
- Kozma's theory of learning with media, and
- Baggett's bushiness hypothesis.

Mayer's Theory of Explanative Illustrations

Richard Mayer's (1993) theory of explanative illustrations is closely related to multimedia and learning. Previous researchers (Atkinson, 1975; Bower, 1972; Levin; 1981a; Paivio, 1971, 1986)

found that pictures or images generated by the learner improved memory for arbitrary lists and paired-associates. Mayer, however, chose to look at more meaningful learning. To examine meaningful learning, Mayer created learning materials with explanative text and illustrations, then measured problem-solving transfer and retention. Explanative text and illustrations describe how a system, such as a bicycle pump, works.

Mayer's (1993) model for learning from text and illustrations is shown in Figure 1. The model has the learning materials as the input, the learner's cognitive system doing the processing, and the learner's performance being the output.

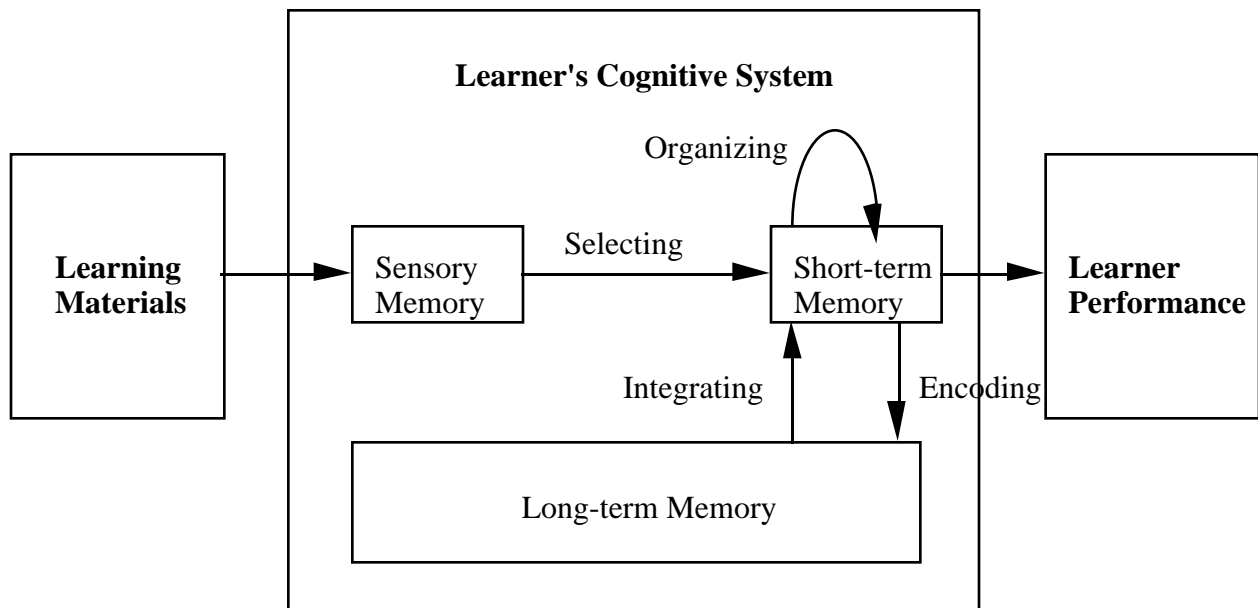


Figure 1. Mayer's (1993) model of the cognitive system for learning from text and illustrations.

The model is supported by the framework shown in Table 1. The learning materials consist of text and illustrations. There are three types of text:

- Narrative text tells a story,
- Descriptive text presents facts, and
- Explanative text tells how something works.

There are four types of illustrations:

- Decorative illustrations are pictures not directly related to the text,
- Representational illustrations show one element described in the text,
- Organizational illustrations show relations between elements described in the text, and
- Explanative illustrations show how the system works.

Learning Materials

Learner's Cognitive System

Learner Performance

<u>Type of Text</u>	<u>Type of Cognitive Process</u>	<u>Type of Performance</u>
Narrative	Selecting	Conceptual retention
Descriptive	Organizing	Non-conceptual retention
Explanative	Integrating	Problem-solving transfer
<u>Type of Illustration</u>	<u>Type of Learner</u>	
Decorative	Low prior knowledge	
Representational	High prior knowledge	
Organizational		
Explanative	<u>Type of Cognitive Outcome</u>	
	Meaningful learning	
	Non-meaningful learning	
	No learning	

Table 1. Mayer's (1993) framework for research on learning from text and pictures.

These types of illustrations are described in more detail shortly.

The model of the learner's cognitive system is similar to other earlier models of information processing (for example, Atkinson & Shiffrin, 1968) and includes three memory stores:

- Sensory memory is a very short-term temporary store for input from, for example, the eyes. Sensory memory is not under the learner's control and a learner is not conscious of the information in sensory memory. Information can be transferred from sensory memory to short-term memory.
- Short-term memory is a limited capacity store that can hold several pieces of information simultaneously. Short-term memory is under the learner's active, conscious, control.
- Long-term memory is a permanent, high-capacity, store of information. A learner becomes aware of information in long-term memory by transferring the information to short-term memory.

Mayer's model of the learner's cognitive system includes three processes:

- Selecting is paying attention to the information in the text or illustration. The selecting process moves information from sensory memory to short-term memory. Mayer believes that when instructional material is interesting, learner's pay more attention to it, and process more information.
- Organizing is the process of building logical connections between pieces of information in short-term memory. Mayer believes that self-directed or autonomous learners are more likely to build these logical, cause-effect relationships than less self-directed or autonomous learners.
- Integrating is the process of building connections from information in long-term memory to information in short-term memory. This process identifies similarities between new information and prior knowledge. Mayer believes that learners who have high amounts of knowledge in the domain will perform this process more quickly than learners who have low domain knowledge. Also, low domain knowledge learners will benefit more from instruction that provides familiar contexts than high domain knowledge learners. These hypotheses are based on a review of

studies on learner aptitude (Snow & Lohman, 1984). These researchers (Snow & Lohman, 1984) concluded that instructions that provide structure and guidance are more helpful to less-skilled students than more-skilled students.

- Encoding moves information from short-term memory to the permanent, long-term memory.

The framework includes three kinds of cognitive outcome:

- Meaningful learning occurs when new information is connected in a logical, understandable way to prior knowledge.
- Non-meaningful learning is arbitrary, unconnected, facts.
- No learning occurs when new knowledge is not acquired.

Learner performance is measured three ways:

- Retention of conceptual information is the ability of the learner to recall the significant components and relationships described in the text. For bicycle pumps, an example of conceptual information (Mayer, 1993, p. 264) is "As the handle is pulled up, air passes through the inlet valve on the piston and fills the bottom of the cylinder between the piston and the outlet valve. As the handle is pushed in, the inlet valve closes and the piston forces air through the outlet valve to the hose."
- Retention of non-conceptual information is the ability of the learner to recall isolated facts or verbatim wordings from the text. For bicycle pumps, examples include isolated facts such as "The first reciprocating pump was invented in the 200's B.C." (Mayer, 1993, p. 264).
- Problem-solving transfer is the ability of the learner to answer open-ended questions about the text that require the learner to make new inferences. For bicycle pumps, these questions may include asking the learner to explain what might be wrong with a broken pump or to design a more efficient pump.

Mayer believes that illustrations affect cognitive processes differently, and, therefore, vary in their ability to support learning. Decorative illustrations take up space on a page but are not directly related to the text. For text about bicycle pumps, a decorative illustration might be a drawing of a boy riding a bicycle. The illustration does not help the learner select pieces of information for building connections to prior knowledge. Decorative illustrations do not affect learning. Representational illustrations show a single element that is described in the text. Representational illustrations affect the selecting process because they direct the learner's attention. For text about bicycle pumps, a representational illustration might be a simple drawing of a bicycle pump. Organizational illustrations show the relationships between significant components in a system. These illustrations affect the selecting and organizing processes by focusing the learner's attention and helping the learner to build connections between illustrated components. For text about bicycle pumps, an organizational illustration might be a drawing of a bicycle pump with labels for each of the major parts. Explanative illustrations show how a system works, including cause and effect relationships. For text about bicycle pumps, an explanative illustration might be a drawing of a bicycle pump with labels for each of the major parts, plus arrows and text describing how the parts work together in sequence (cf. Mayer & Gallini, 1990). Explanative illustrations affect the selecting, organizing, and integrating processes and very effectively improve learning.

Mayer believes that explanative illustrations are effective because they help the learner build a mental model that includes meaningful connections to prior knowledge. For bicycle pumps, this prior knowledge might include the behavior of pressure and vacuums. According to Mayer, explanative illustrations need to show the components of a system, the possible states for each component, and the relations between a change in the state of one component and a change in the state of another component (including the principles by which the components are connected in the system). Also, explanative illustrations need to use familiar knowledge, such as an analogy.

Studies (Bayman & Mayer, 1988; Bromage & Mayer, 1981; Mayer, 1975, 1976, 1980, 1983, 1989a; 1989b; Mayer & Anderson, 1991, 1992; Mayer, Dyck, & Cook, 1984) found that explanative illustrations improved conceptual retention, improved problem-solving transfer, and decreased non-conceptual retention. Mayer (1993) believes that the following cognitive conditions are necessary for illustrations to be effective: (1) the text explains how the system works (rather than simply listing system components), (2) the illustration summarizes key system components, component states, and the relationships of component states between components (allowing the learner to create a cause-effect chain), (3) the learners have low domain knowledge (because the explanative text and illustrations are more helpful for building an appropriate mental model; high domain knowledge learners can build a mental model from text alone), and (4) the performance tests are appropriate for the type of illustration being studied (for example, if the illustration is explanative, don't test for number of facts recalled; instead test for problem-solving transfer).

So, Mayer's theory of explanative illustrations supports the idea that new knowledge is connected to prior knowledge. Since they have more connections available, Mayer believes that people with high prior domain knowledge will learn new information in that domain easier than people with low prior domain knowledge. Mayer believes that text and explanative illustrations improve learning by helping people see how system components are connected and affect each other. Text and explanative illustrations help the learner build a mental model of the system being taught.

Paivio's Dual Coding Theory

Allan Paivio's (1971, 1991; Clark & Paivio, 1991) dual coding theory is relevant to multimedia information presentation and learning. According to Paivio, information is processed through one of two generally independent channels. One channel processes verbal information such as text or audio. The representations of information processed by this system are known as logogens (from Morton, 1969). The other channel processes nonverbal images such as illustrations and sounds in the environment. The representations of information processed by this system are known as imagens. Both kinds of representational units are concrete, modality-specific (e.g., visual versus auditory versus sensorimotor) analogues rather than abstract, amodal structures.

Logogen and imagen representational units are connected by three processes so that activation (scan of long-term memory) can spread between units. The interconnections have varying activation strengths, so activation flows probabilistically from a stimulus through the links. In this way, a word can evoke a picture and a picture can evoke a word. Representational processing is the direct activation of logogens (verbal representations) by linguistic stimuli and the direct activation of imagens (imaginal representations) by nonverbal stimuli. For example, the word "dog" can trigger an association with the "dog" logogen. According to Paivio, all cognitive tasks involve representational processing. Referential processing is activation that goes across the two representational systems. For example, the word "dog" can activate an image of the person's pet dog Spot. Associative processing is activation within one representational system. For example, the logogen "dog" can trigger an association with the logogen "cat."

Information can be processed through both the verbal and nonverbal channels. This occurs, for example, when a person sees a picture of a dog and also processes the word "dog." Information processed through both channels has an additive effect on recall (Mayer & Anderson, 1991; Paivio & Csapo, 1973), possibly because the learner has more cognitive paths that can be followed to

retrieve the information. Paivio (1967, 1991) calls this expectation the additivity hypothesis. For example, information that uses text and relevant illustrations will likely be learned better than information that uses text alone (verbal channel only), audio alone (verbal channel only), combined text and audio (verbal channel only), or illustrations alone (image channel only).

One limitation of the dual coding theory is that it is generally applied to specific, concrete, easy to image nouns such as "lamp." Using paired associates, Paivio (1963, 1965) found that nouns were better remembered than adjectives, and that concrete nouns (e.g., "inventor") were better remembered than abstract nouns (e.g., "interpretation"). Apparently (Paivio & Foth, 1970; Rowe & Paivio, 1971), the concreteness of the paired associates (e.g., "ingenious-inventor") allowed the learner to integrate the two items into a single image.

Paivio (1975) successively presented concrete items that included repeated pictures, repeated words, and picture-word combinations. People recalled more items that were successively presented as picture-word combinations compared to repeated pictures or repeated words. Paivio believes that this effect resulted because people differentially encoded the successive picture-word combinations. People also recalled more successively repeated pictures than successively repeated words. Paivio believes that this is because people recall pictures better than words. This result is known as the picture superiority effect (Nelson, Reed, & Walling, 1976; Paivio, Rogers, & Smythe, 1968) and may be because pictures access semantic meaning more quickly and completely than words (Smith & Magee, 1980; Nelson, 1979).

Paivio's dual coding theory emphasizes that there are two modes of representation in memory—verbal and visual (this concept is also supported by Rollins and Thibadeau, 1973). Information is stored in the representation mode that most closely matches its presentation. The concept of dual coding is challenged by other investigators (e.g., Anderson, 1978; Anderson & Bower, 1973; Kieras, 1978; Kosslyn, 1980, 1981; Norman & Rumelhart, 1975; Pylyshn, 1973, 1981; Shepard, 1978) who believe that information is stored in a single, abstract memory.

So, Paivio's dual coding theory supports the idea that people learn by connecting new knowledge to prior knowledge. People learn better when the learning materials involve related verbal and pictorial information compared to verbal material alone or pictorial material alone. It also appears that information presented through the pictorial channel is more salient and better remembered than information presented through the verbal channel.

Kozma's Theory of Learning with Media

In Robert Kozma's theoretical framework, learning is "an active, constructive process whereby the learner strategically manages the available cognitive resources to create new knowledge by extracting information from the environment and integrating it with information already stored in memory" (Kozma, 1991, pp. 179-180). Many factors affect the ability to learn from media, including the construction of representations, the operations performed on the representations, characteristics of the medium, instructional designs, characteristics of learners, and characteristics of the learner's tasks.

According to Kozma, the symbol systems and information processing capabilities of a medium are important influences on the ability to learn the information presented by that medium. Symbol systems are the elements used to communicate via the medium. For example, a textual story uses words and sentences as symbols for objects and actions. Television uses pictures and audio-linguistic symbols. The symbol systems used by media influence the ability of a learner to process the information they represent. Some symbol systems are more closely matched with their representations in human memory. For example, pictorial symbols are a close match with images in memory. The information represented by these symbol systems is easier to learn than the information represented by symbol systems that are not closely matched by their representations in memory. Also, some symbol systems are better at representing certain information than other

symbol systems. For example, a picture is better than a thousand words when it comes to constructing a mental model of a machine's operation. The symbol systems affect the mental skills needed to process the information and, hence, the learner's mental models.

Media most effectively help people to learn when the media's capabilities are used by the instructional method to provide representations or cognitive models that are important to the learning task that learners cannot do for themselves. For example, the stability of text and the ease with which a reader can slow reading speed or re-read a confusing sentence helps people learn. Television's unique ability to show motion helps people acquire motion-based information. The ability of a computer to transform numerical information into easier to understand graphical displays (e.g., bar charts) is a powerful learning aid. Kozma believes that the most outstanding aspect of learning from computerized multimedia is the ability to integrate the learning advantages for each of several media.

So, according to Kozma, new information is connected to prior information. This process is facilitated when the symbol systems used by the media are consistent with the representations used in human memory. Media and instructional methods can help people process information to create memorable mental models.

Baggett's Bushiness Hypothesis

Patricia Baggett's (Baggett, 1984, 1989; Baggett & Ehrenfeucht, 1982; 1983) bushiness hypothesis assumes that conceptual memory is a semantic network in which the nodes are concepts. Concepts are formed from different media sources, including text and pictures. When a concept is formed, it is connected to existing concepts in the network. Each concept has associations. For example, if a person reads the word "red," the person can connect this stimulus to a visual concept that is a red ball.

The bushiness hypothesis asserts that people can form more connections with visual concepts than verbal concepts. Visual concepts are richer or "bushier" than verbal concepts. For example, a concept formed from seeing a physical red block can be associated with verbal concepts such as "red block" as well as with other physical concepts such as "rod."

Baggett (1984) showed people simple physical objects from an assembly kit. Some people saw each object (visual concept), then heard the object name (verbal concept). Other people heard the object name (verbal concept), then saw the object (visual concept). On recognition tests taken immediately or seven days later, the people who saw the objects first remembered more object names than the people who heard the object names first. Baggett suggested that these results were obtained because the visual concepts were "bushier" than the verbal concepts. The visual concepts had more associations available for linking with the subsequently presented verbal concepts.

Baggett's bushiness hypothesis is consistent with the work of other researchers. Bower (1970) believed that visual information was a richer source of relational associations than verbal information. A study by Peeck (1974) supported the idea that pictorial media are more salient than textual media. When children read parts of a story in which the pictures did not match the text, the students answered more questions using the pictorial information than the textual information. Pezdek and Stevens (1984) found that when audio and video were mismatched in a videotaped segment of Sesame Street, five year old children comprehended less auditory information than video information. These results are consistent with the visual-dominance effect (cf. Posner, Nissen, & Klein, 1976).

So, Baggett's bushiness hypothesis supports the idea that new concepts are connected to prior concepts. Like Paivio, her work suggests that visual information is more salient ("bushier") than verbal information. Baggett believes that visual information has more connections available for linking than verbal information.

Chapter Summary

There appears to be a theoretical basis for the assumption that multimedia can help people learn. This chapter on learning theory supports two general conclusions. First, people learn by connecting new knowledge to old knowledge. These connections make the new information better organized, interpretable, and meaningful. The new knowledge is also easier to retrieve because existing, familiar retrieval techniques may be used. People with high prior domain knowledge appear to have more connections available to link with new knowledge in that domain than people with low prior domain knowledge. These extra connections result in improved learning compared to low prior domain knowledge learners. So, if multimedia helps people connect new knowledge to old knowledge, multimedia should help people learn.

Second, elaboration increases the number of connections between new knowledge and old knowledge, resulting in improved learning. New knowledge that is richer, "bushier," more elaborated is easier to connect to prior knowledge and is learned better. Semantic processing is richer than the processing of text appearance. Pictorial information is richer than verbal information. So, if multimedia information is rich, allowing people to elaboratively process the information and make more connections to prior knowledge, then multimedia information should improve learning.

Chapter 2 Classroom Lecture versus Multimedia

The preceding summary of general and specific learning theories predicts that, when used appropriately, multimedia information presentation should help people learn. Compared to learning materials that don't use multimedia, multimedia learning materials may be richer, provide more opportunities for elaboration, and have more cognitive connections available for the learner to link the new knowledge with prior knowledge.

The current, standard form of education is classroom lecture. To be of value to society, multimedia instruction should be more effective than classroom lecture. The following literature review examines the results of empirical studies of classroom lecture versus multimedia learning to answer the question, "Do people learn better with multimedia instruction or classroom lecture?"

Meta-analyses examining over 200 studies (Bosco, 1986; Fletcher, 1989, 1990; Kulik, Bangert, & Williams, 1983; Kulik, Kulik, & Bangert-Drowns, 1985; Kulik, Kulik, & Cohen, 1980; Kulik, Kulik, & Shwalb, 1986; Schmidt, Weinstein, Niemic, & Walberg, 1985) compared learning information in a traditional classroom lecture format versus learning the same information on a computerized multimedia system. The students were in K-12, higher education, industry, and the military. The learning information included biology, chemistry, foreign languages, and electronic equipment operation. The control group usually learned the material via classroom lecture or instruction with hands-on equipment experience while the comparison multimedia groups usually received instruction via interactive videodisc or some other kind of computer-based instruction. Learning was most often measured using tests of achievement or performance. Learning was generally found to be higher with the computer-based multimedia systems than with the traditional classroom lectures.

Another very significant finding was that learning appeared to take less time when multimedia was used. For example, Kulik, Bangert, and Williams (1983) found one study that recorded a 39% savings in learning time with computerized instruction (135 minutes) versus classroom instruction (220 minutes) and another study that recorded an 88% savings in time (90 minutes for computer instruction versus 745 minutes for classroom instruction). Both studies involved computer simulation instruction in physics. In a comparison involving eight studies, Kulik, Kulik, and Cohen (1980) found that computer-based instruction took about 2.25 hours per week while traditional classroom instruction took about 3.5 hours of instruction per week (a 36% savings). Kulik, Kulik, and Shwalb (1986) identified 13 studies in which students using computers mostly for tutoring learned in 71% less time than students in traditional classroom instruction.

It appears that computerized multimedia information presentation may sometimes be superior to traditional classroom presentations of information. However, multimedia itself may not be the only source of the learning differences. In these studies, there are other competing explanations for the differences in learning. These alternative explanations include instructional methods, the effects of stimulation, and effects on student attitudes.

Instructional Methods

It is not clear whether the results of these studies were due to the multimedia or to the different instructional styles. It is not possible to unequivocally assign responsibility because both factors change together. The instructional method for computer-based multimedia is different than the instructional method for traditional classroom lecture. It is possible that putting material on a computerized multimedia system, such as computer-based training, forces the instructor to better organize and structure the material compared to the classroom lecture. Better-organized material may be easier to learn than less-organized material. Learning differences found between computerized multimedia and traditional classroom lecture may be due to the different instructional methods.

When the same person develops the same material for classroom instruction and computerized multimedia instruction, then any learning differences may more likely be due to the multimedia than to the instructional method. Analysts (Clark, 1983, 1985; Clark & Craig, 1992; Kulik, Kulik, & Cohen, 1980) found almost no learning differences in these cases. But learning differences did occur when a different person or team developed each set of instructional materials. These results suggest that it may not be the multimedia, but the instructional method that may be responsible for learning advantages.

Stimulation

One explanation for the apparent success of computerized multimedia information presentation over traditional classroom lecture is that multimedia is stimulating. Multimedia information presentation captures students' attention, and attentive students learn more. This explanation has some support from empirical studies. An analysis (Clark, 1983, 1985; Clark & Craig, 1992; Kulik, Bangert, & Williams, 1983) of several multimedia studies found that, compared to traditional classroom lecture, learning was higher for groups that used multimedia for four weeks or less (0.5 standard deviation improvement in scores), but tailed off fairly strongly after eight weeks (0.2 standard deviation improvement in scores). It appears that as the multimedia novelty wore off, the learning advantages decreased. The stimulation of multimedia information presentation may have a slight, temporary, positive effect on learning.

Multimedia Improves Student Attitudes

Multimedia may be effective because it improves students' attitudes toward the learning material. For example, students liked the learning material in videodisc-based instructional environments better than the learning material in traditional classroom lectures (Bosco, 1986; Fletcher, 1989, 1990). Fourth grade students preferred to learn Newton's laws of motion using animated graphics rather than static graphics (Rieber, 1991). It also appears that pictures may improve student attitudes toward learning (Bosco, 1986; Fletcher, 1989, 1990; Kulik, Kulik, & Cohen, 1980).

Other studies found that students gave higher ratings of interest and enjoyment to picture-word diagrams that had color drawings compared to block-word diagrams that did not have drawings (Holliday, Brunner, & Donais, 1977), textual material that included small, unrelated cartoons compared to textual materials without illustrations (Sewell & Moore, 1980), stories with drawings than stories without drawings (Samuels, Biesbrock, & Terry, 1974), and text books with drawings than text books without drawings (Bryant, Brown, Silberberg, & Elliot, 1980; Rigney & Lutz, 1976; Sewell & Moore, 1980). For example, college students reported that they were more likely to purchase a psychology text book that included illustrations than one that did not (Bryant, Brown, Silberberg, & Elliot, 1980).

However, improved student attitudes do not necessarily result in improved learning. Adding illustrations that did not show information in the text did not improve learning (Levie & Lentz, 1982; Sewell & Moore, 1980). Similar results were obtained for an audio tape using illustrations presented via slides (Baker & Popham, 1965; Popham, 1969).

So, although instructional method is an alternative explanation for the improved learning associated with computerized multimedia information presentation compared to traditional classroom lecture, stimulation and attitude do not appear to play significant roles. The media or the instructional method appear to be responsible for learning improvements compared to traditional classroom lecture.

Multimedia versus "Monomedia"

The preceding section compared learning the same information with computerized multimedia to learning in the traditional classroom lecture. Instructional method appears to be a competing explanation for learning differences in these two conditions. To separate the effects of media versus instructional method, this section reviews empirical studies in which the information and

instructional method were kept the same, but multimedia was used in one condition and "monomedia" was used in the other condition. For example, this situation occurs when the same verbal information is presented using audio and printed text together (multimedia) versus audio text alone ("monomedia"). Any performance differences found in these conditions can be ascribed to the media rather than the instructional method.

Some studies (Levie & Lentz, 1982; Mayer & Anderson, 1991, 1992; Menne & Menne, 1972; Pezdek, Lehrer, & Simon, 1984; Severin, 1967) looked at this kind of information presentation. These studies found that two redundant media seem to improve learning better than one medium. For example, Mayer and Anderson (1991) had college students (1) hear a verbal description simultaneously with an animation explaining how a bicycle pump works, (2) hear the verbal description only, (3) see the animation only, or (4) receive no training. On a problem-solving test, the students who heard a verbal description simultaneously with the animation performed better than the other students. The Menne and Menne (1972) study found that third grade students verbally recalled simple, four-line verses better with an auditory/visual presentation than auditory alone or visual alone.

However, other studies (Mayer & Anderson, 1992; Palmiter & Elkerton, 1991; Rohwer & Harris, 1975; Severin, 1967; Van Mondfrans & Travers, 1964) found that redundant media did not improve learning. For example, Palmiter and Elkerton (1991) taught people computer user-interface steps by (1) an animated demonstration of the steps on the computer screen, (2) procedural textual instructions on the computer screen, or (3) combined animated demonstration and auditory procedural instructions. The study participants completed a test of the learned computer-interface steps immediately and seven days later. On the immediate test, the demonstration only group was as accurate as the demonstration combined with text group, and both groups were more accurate than the text only group. The addition of the auditory verbal medium did not appear to improve immediate learning. However, on the delayed test, the text only group was more accurate than both demonstration groups. It appears that the group that learned using one medium (text only) learned better than the group that learned using two media (demonstration and auditory verbal). In the Severin (1967) study mentioned earlier, a group that learned with two media (audio combined with print) did not show better animal name recognition than a group that learned with one medium (print alone).

The effects of conceptual processing, attention, media salience, number of presentations, dual coding, and differential encoding appear to partially explain these inconsistent results. For example, in the Mayer and Anderson (1991) study, the students who heard a verbal description simultaneously with an animation performed better on a problem-solving test than students who only heard the verbal description or only saw the animation. These findings may have been obtained because the combined media more easily allowed the students to create a mental model of the system than each medium alone. In the Palmiter and Elkerton (1991) study, the students who learned the user interface procedures via text outperformed students who learned via animation and text. This unexpected result may have been obtained because the text only group had to perform active encoding but the animation and text students passively watched the highly salient animation, ignored the auditory verbal information, and probably encoded the procedural steps less well. The Menne and Menne (1972) study found learning improvements for four-line verses when third grade students heard and saw the text than when the students only heard or only saw the text. This learning advantage may be due to the extra presentation that the redundant medium offered. In the Severin (1967) study, the students who received the same information via two redundant verbal media did not outperform students who received the information via a single medium, possibly because the additional presentation was not helpful for short information (cf. Paivio, 1975) and the redundant verbal media did not offer any dual coding benefits. In fact, Severin (1967) found that audio with relevant pictures produced the best learning performance. Similarly, Nugent (1982) obtained the highest learning levels when students were presented information via combined text

and pictures or combined audio and pictures compared to the same content presented via text alone, audio alone, or pictures alone.

Chapter Summary

Although computerized multimedia appears to improve learning compared to traditional classroom lecture, instructional method is a possible alternative explanation for these results. However, the reported decrease in time needed to learn the information (Bosco, 1986; Fletcher, 1989; Kulik, Bangert, & Williams, 1983; Kulik, Kulik, & Cohen, 1980; Kulik, Kulik, & Shwalb, 1986) is a potentially significant advantage for computerized multimedia.

The use of redundant media is not generally associated with consistent learning advantages. But specific applications of redundant multimedia information presentation appear to be effective, especially when the information helps learners to create mental models or to develop dual code associations.

Chapter 3 Factors Affecting Effectiveness of Multimedia on Learning

Instruction using multimedia information presentation appears to be a potential learning advantage compared to traditional classroom instruction. To try to determine the source of this possible advantage, this chapter reviews a wide variety of empirical studies from psychology, education, and computer science to identify factors that appear to influence the ability to learn from multimedia information. This chapter also includes possible theoretical explanations for the existence of each factor. The factors will be discussed using a general organizational framework for learning that was developed by Bransford (1978).

Bransford's Framework for Learning

Based on a framework developed by Jenkins (1978), John Bransford's (1978) organizational framework includes four basic factors that need to be considered when evaluating questions about learning, understanding, and remembering. The four factors occur in a variety of learning situations, including courses taught using computerized multimedia such as computer-based tutorials. Bransford's framework for learning is shown in Figure 2.

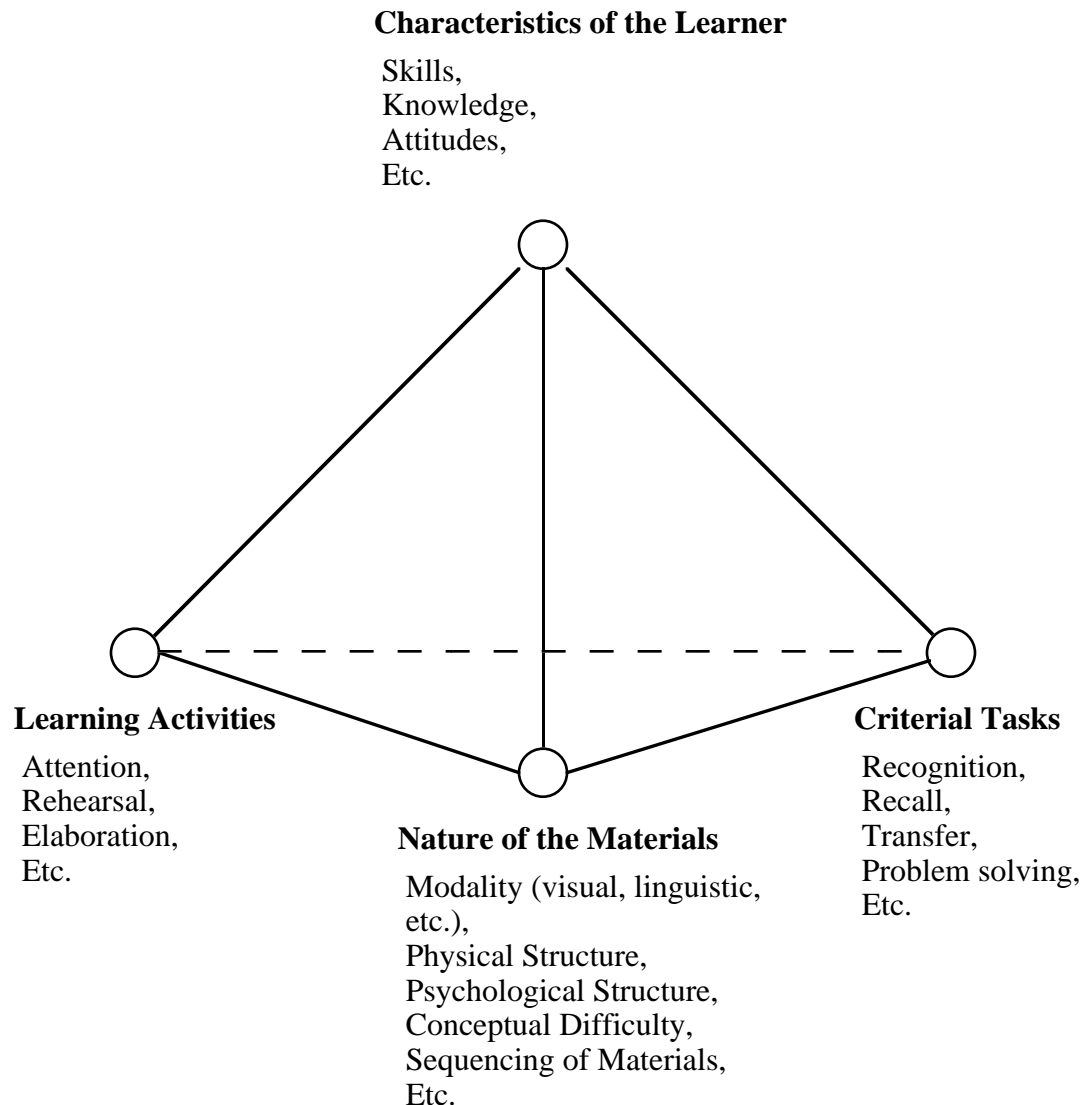


Figure 2. Bransford's (1978) framework for learning.

The first factor is the nature of the materials. The learning materials can vary significantly, including their modality, physical structure, psychological structure, conceptual difficulty, and sequence. The second factor is the characteristics of the learner, including the learner's current skills, knowledge, and attitudes. The third factor is the learning activities. This factor addresses what the learner does with the learning materials, and includes attending to the information, rehearsing it, and elaborating it. The fourth factor is the criterial tasks, the type of tests used to measure learning, and includes recognition, recall, transfer, and problem-solving. Each type of test may reflect a different assumption of what "learning" means.

According to Bransford, all four factors must be considered when examining learning. For example, the characteristics of the learner affect the effectiveness of the learning materials. If a learner did not understand key concepts that the teacher assumed were learned previously, then the follow-on course materials would be less effective. Similarly, if a student performed extensive rehearsal activities to rote memorize learning materials, but was given an essay test instead of the expected multiple choice test, then learning performance would suffer. Learning is affected by all four factors. To understand a learning situation, all four factors must be considered simultaneously.

Bransford's (1978) organizational framework for learning is an appropriate way to structure discussion of the wide variety of factors that affect the ability of multimedia information presentation to help people learn.

Nature of the Materials

Bransford's (1978) first factor is the nature of the materials. Learning material characteristics include modality, physical structure, psychological structure, conceptual difficulty, and sequence.

Motion

Motion can improve or degrade learning. Using motion in a visual display can focus the learner's attention on a specific item, resulting in improved learning. For example, McGuire (1961) used a film to teach college students a pursuit rotor tracking task. In one condition, the entire film was run at regular speed. In the other condition, specific instructional segments of the film were run at a slow speed and the remaining segments were shown at regular speed. People learned the tasks shown in slow motion better than the tasks shown at regular speed. Roshal (1961) had over 3,000 Navy recruits learn knot tying using a film that showed motion or a film that showed static images. Knots were tied more accurately when the recruits saw the film showing motion. Lumsdaine, Sulzer, and Kopstein (1961) got similar results using animated or non-animated (static image) films to teach 1,300 Air Force trainees how to read micrometer settings.

Baek and Layne (1988) presented computer-assisted tutorial information to high school students via text, static graphics, or animated graphics. The purpose of the material was to teach the students the mathematical rule for calculating average speed. Learning was measured by performance on problems and answers to multiple choice and short answer questions. Learning was best in the animated graphics condition.

It appears that motion focused the students' attention on important information that was being shown by the motion. Motion improved the students' ability to organize and process information in a way that is consistent with Mayer's (1993) belief that explanative illustrations support learning better than decorative illustrations. These results are also consistent with Kozma's (1991) belief that learning is facilitated when the presentation medium provides representations that are important to the learning task, but are hard for learners to create for themselves.

However, other studies (cf. Carpenter & Just, 1992; Rieber, 1990) found that motion did not improve learning. For example, Carpenter and Just (1992) used text, static drawings, and animated drawings to teach college students the structure and function of simple mechanical

systems composed of levers, gears, and ratchets. The researchers measured the ability of the students to answer questions about the motions of specific system components and to make accurate drawings of the mechanical systems. Overall, text and animation did not improve learning compared to text and static drawings. For students with low prior mechanical knowledge, the researchers believed that animations and text were helpful only when the text directed the students' attention to the motion of specific system components. Although animations did not help the high prior mechanical knowledge students either, the researchers believed that the overall superior performance of the high prior knowledge students was due to their ability to create better mental models of the mechanical systems.

It appears that motion is effective when it helps the learner pay attention to and learn information that is related to motion. Some students, especially students who have little prior knowledge of the domain being learned, may have difficulty identifying what is important to learn. As a result, motion without an obvious purpose can mislead attention, produce cognitive overload (Park & Hopkins, 1993), and reduce learning.

Park and Hopkins (1993) reviewed empirical studies involving dynamic and static visual displays. They defined a dynamic visual display as "the presentation of any type of pictorial and graphical movement during instruction" and a static display as the presentation of any type of pictorial or graphical information "characterized by no movement or object manipulation" (Park & Hopkins, 1993, p. 427). After examining conditions in which motion (dynamic displays) helped people learn, Park and Hopkins (1993) developed six general recommendations for when to use motion to improve learning. First, to demonstrate sequential actions in a procedural task. Video or animation can help a novice learn by showing an expert actually performing the steps to, for example, repair a piece of equipment. Second, to simulate causal models of complex system behaviors. Motion is very effective at showing the relationships between manipulation of one control in a system and its effect on other controls and displays. Computer-based flight simulators typify this use of motion. Third, to show otherwise invisible system functions and behaviors. Graphical animations can make it possible to "see" the function of electronic systems or blood flowing through the human body. This visual manifestation may help the learner to develop explanatory mental models. Fourth, to show a task that is hard to describe verbally. For example, animations can make it easier to learn about simultaneous, parallel chemical reactions that would have to be described sequentially. Movement can also help deaf students to communicate. Fifth, to provide a visually motional cue, analogy, or guidance. For example, a graphical animation can convert formulae to show an object's trajectory. Seeing the trajectory may enable the learner to create a mental model that supports problem-solving. Sixth, to focus attention on specific tasks or displays. To learn how to pilot an aircraft, the one or two most important controls and gauges can highlight at especially appropriate times to guide the learner. This kind of highlighting is not available in an actual, physical, real-time system.

Media

The media used to present the instructional information appear to affect learning. Depending on the learning material and the test of learning, some media appear to be more effective than others. For example, Baggett (1979) had college students see a silent movie or hear an equivalent story. The students who saw the movie wrote more complete summaries a week later. For writing short story summaries, the visual, silent movie was more effective than the auditory presentation. Hayes, Kelly, and Mandel (1986) obtained similar results using television and radio versions of the same story. Preschool children saw and heard a television version of a short story or heard a radio version of the same story. On tests of immediate recall of story content, children who heard the radio version made more errors than children who saw and heard the television version.

These result may have been obtained because information absorbed through the visual channel is richer and more easily connected to other information than information absorbed through the verbal channel. This interpretation is consistent with the picture superiority effect (Nelson, Reed, and

Walling, 1976; Paivio, Rogers, & Smythe, 1968), Paivio's (1971; 1991; Clark & Paivio, 1991) dual coding theory, and Baggett's (1984) bushiness hypothesis.

For short messages or lists that are recalled a short time later, an auditory presentation was better than a visual presentation (Hapeshi & Jones, 1992; Penney, 1975; Watkins & Watkins, 1980). For example, in a study by Das and Sui (1989), auditory media were more effective than visual media for children performing oral serial recall of words. One explanation for these results is that the short lists of words may be retained in and recalled from a short-term echoic memory (such as Baddeley's (1983, 1988b) articulatory loop system), making the auditory presentation more facilitative than the visual presentation. When children saw, heard, or saw and heard commercials embedded in a short story, the children who saw or saw and heard the short story recognized more advertised products than the children who only heard the short story (Stoneman & Brody, 1983). For recognizing advertised products in a short story, auditory-visual and visual media were more effective than auditory media alone. These results are consistent with the picture superiority effect (Nelson, Reed, and Walling, 1976; Paivio, Rogers, & Smythe, 1968), Paivio's (1971, 1991; Clark & Paivio, 1991) dual coding theory, and Baggett's (1984) bushiness hypothesis.

Another study (Baggett & Ehrenfeucht, 1983) found that college students recalled more information when auditory, verbal narration was synchronized with a movie than when the narration was presented before or after the movie. However, when the students read, rather than heard, the narration, this advantage disappeared. For information recall, the textual medium was more effective than a narrated movie. Craik's (Craik & Lockhart, 1972; Craik & Tulving, 1975) depth of processing approach is a reasonable explanation for these findings. The textual information may have been processed more deeply than the narrated movie, possibly because the text required the active, focused participation of the student but the movie allowed the student to take a more passive role. This analysis is consistent with a suggestion (Aldrich & Parkin, 1988) that listeners take a more passive role than readers, find it harder to concentrate, and therefore learn less than readers. This analysis is also consistent with findings (Jacoby, Craik, & Begg, 1979; Salomon, 1984) that information retention is positively affected by the effort (e.g., difficulty of semantic judgments or amount of concentration) used to process the information. For example, Salomon (1984) found that sixth grade children thought that a textual print story was harder to learn from and required more effort than a closely matched silent movie on television, but the children who read the text made more story inferences than the children who saw the silent movie.

Dwyer (1967) taught college students heart anatomy using similar explanative information presented via (1) a recorded oral presentation with only names of parts of the heart presented visually, (2) the same oral presentation with simple line drawings that included names of parts of the heart presented visually, (3) the same oral presentation with detailed, shaded drawings that included names of parts of the heart presented visually, and (4) the same oral presentation with realistic photographs that included names of parts of the heart presented visually. On a composite test of identification, terminology, drawing, and comprehension, students did better using the simple line drawings and detailed, shaded drawings than the oral presentation alone or the realistic photographs. The simple drawings were more effective than the realistic photographs, possibly because the photographs provided too much information for novice anatomy students to attend to, organize, and connect to prior knowledge. This interpretation is consistent with the suggestion by Park and Hopkins (1993) that motion without an obvious purpose can mislead students' attention, produce cognitive overload, and disrupt learning.

In a review of the literature on text and illustrations, Levie and Lentz (1982) found that text that was accompanied by illustrations showing what was described in the text was learned better by children than text that was not accompanied by illustrations. For example, Peeck (1974) asked fourth grade children to read a story with or without supportive illustrations, measured learning via multiple choice, verbal recognition tests, and found that retention was better with illustrated text. Levie and Lentz estimated that children reading illustrated text learned one-third more than children

reading non-illustrated text, especially when the illustrations supported information presented in the text. This conclusion is consistent with Mayer's (1993) belief in the superiority of explanative illustrations over decorative illustrations. Explanative illustrations may allow the student to build more connections to prior knowledge than unrelated decorative illustrations. Illustrations may also make abstract relationships more concrete and simplify the complex (Winn, 1987, 1989).

A study by Bransford and Johnson (1972) supports this idea. Bransford and Johnson (1972) presented short, ambiguous text passages to high school students. Before seeing the passages, one group of students saw a picture that explained the ambiguous text. The researchers believed that this picture provided a context for understanding the ambiguous text. The students who saw the picture recalled more ideas from the text than the students who did not see the picture. It appears that the picture allowed the students to interpret the meaning of the text, organize it, then connect it to other concepts in memory.

Levie and Lentz (1982) also found that illustrations that did not show what was described in the text did not improve learning. For example, Sewell and Moore (1980) added to textual material small cartoons that did not support the textual information. Although the students enjoyed the cartoons, the cartoons did not affect learning. Evans and Denney (1978) found that the short phrases in picture-phrase combinations were recalled better as the pictures and phrases became more related. Using verbal captions, Bahrck and Gharrity (1976) showed that pictures helped people recall captions that were related to the pictures, but not captions that were unrelated. These results suggest that the mere presence of illustrations does not improve the learning of textual information. The illustrations must show information that is presented in the text. It appears that supportive illustrations allow learners to build referential connections between the verbal and pictorial information (Paivio, 1971, 1991; Clark & Paivio, 1991), and improve memory and learning.

Synchronization of Media

The order in which media are sequenced appears to affect learning. For example, Baggett and Ehrenfeucht (1983) arranged for college students to see and hear a narrated movie on carnivorous plants or to first see the movie without narration, then hear the narration. On 63 true-false, multiple choice, and short answer questions, the students who saw the movie and heard the narration simultaneously scored higher than the students who saw the movie without narration, then heard the narration. The researchers believed that this result demonstrated support for Paivio's (1971, 1986) dual coding hypothesis. Also, simultaneous presentation of the verbal and pictorial media may have helped the students to form representations that facilitated learning, but were difficult to form on the sequential presentation (Kozma, 1991).

In the same study, other groups of students (1) saw the movie without narration, then heard the narration, or (2) heard the narration, then saw the movie without narration. The group that saw, then heard scored higher than the group that heard, then saw. This result suggests that it was easier to link auditory information to prior visual information than to link visual information to prior auditory information. This may be because the see-hear group used the earlier visual information to form concepts, but the hear-see group formed concepts using other visual information rather than the verbal information that was just presented.

Baggett (1984) obtained similar results. College students learned the names of 48 pieces of an assembly kit by watching a film that showed each item and listening to a verbal narration that named each item. The film was run with the visuals shown seven seconds, 14 seconds, or 21 seconds before the narration, the visuals shown in synchrony with the narration, or the narration heard seven seconds, 14 seconds, or 21 seconds before the visuals. Learning was measured by asking the students immediately or seven days later to provide the assigned name for each of 48 photographs of assembly pieces. The highest scores were found for the group shown the visuals only seven seconds before the narration and for the group who received the visuals in synchrony

with the narration. It appears that students were better able to form interconnections when the visual information was presented before or with the verbal information. Gropper (1966) obtained similar facilitating effects when science information was presented in pictorial-verbal sequence rather than verbal-pictorial sequence. The visual medium appears to be richer and more salient than the auditory medium (also see Peeck, 1974).

Mayer and Anderson (1991, 1992) performed a series of studies in which mechanically naive college students watched an animation showing how a bicycle pump or automobile drum brakes worked and heard a verbal explanation. The verbal explanation was presented before the animation or during the animation. The students who heard the verbal explanation with the animation performed higher on a creative problem-solving test than the students who heard the verbal explanation before the animation. The researchers believed that the results supported Paivio's (1971, 1986) dual coding hypothesis and concluded that pictures and words are most effective when used together.

Interactivity

Interactivity can be thought of as mutual action between the student, the learning system, and the learning material (Fowler, 1980). Interactivity appears to have a strong positive effect on learning from multimedia (Bosco, 1986; Fletcher, 1989, 1990; Verano, 1987). One researcher (Stafford, 1990) examined 96 learning studies and, using a statistical technique called effect size (difference between means of control and experimental group divided by standard deviation of the control group), concluded that interactivity was associated with learning achievement and retention of knowledge over time. Similar examinations of 75 learning studies (Bosco, 1986; Fletcher, 1989, 1990) found that people learn the material faster and have better attitudes toward learning the material when they learn in an interactive instructional environment.

A well-controlled laboratory study (Slamecka & Graf, 1978) found support for fundamental aspects of interactivity. Slamecka and Graf (1978) had college students read or generate the second word in a paired associate. For example, the read group saw "rapid-fast." The generate group saw "rapid-f" and was asked to provide a word beginning with "f" that was associated with "rapid." Here, a good word is "fast" (e.g., "rapid-fast"). The participants read or generated words for a 100-item list. Under a variety of generate rules (e.g., associates, opposites, synonyms), number of trials (e.g., one to five trials), expected or unexpected memory tests, and kinds of memory tests (e.g., free recall, cued recall, uncued recognition, cued recognition) learning was better when participants actively generated words than when participants passively read words. This phenomenon is known as the generation effect.

A more applied study (Dean & Kulhavy, 1981) also supports the generation effect. Dean and Kulhavy (1981) asked students to learn the features of a fictitious country. One group of students read text describing the locations of the features while the other group drew a map of the country as they read the same text. The students who drew the map did better on a comprehension multiple choice test. In another experiment, one group of students studied a map on which the features were labeled while another group copied the features and labels onto a blank map. The students who were forced to actively process the spatial information by copying the map performed better on a free recall test of the map information.

Finally, anecdotal evidence supports the value of interactivity for learning. In New York City's School of the Future, seventh and eighth graders use multimedia computers, databases, and authoring software to create multimedia reports for French and biology classes. The students "get, understand, and manipulate—or GUM—information" (Schwartz, 1991, p. 158 quoting Gwen Solomon). Students are thought to become active, exploratory learners who integrate and organize information. Since the active learning technique was implemented, daily attendance at the school improved from 86.5% to 98%. At a similar school, a researcher said that "you can tell they're learning by the smart questions they're raising" (Schwartz, 1991, p. 162 quoting Kathleen

Wilson). Active, exploratory learning is consistent with the recommendations of Constructionism. According to this theory, people learn by building. Learning is the development of knowledge structures, and "this happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a theory of the universe" (Papert, 1991, p. 1).

It is possible that interactivity increases the active involvement of the student, focuses the student's attention on the information being learned (Mayer, 1993), and causes information to be processed more elaboratively (Anderson, 1980, 1983; Anderson & Reder, 1979; Stein & Bransford, 1979; Reder, 1979) or more deeply (Craik & Lockhart, 1972; Craik & Tulving, 1975). Information that is processed in this way is easier to connect to long-term memories and may therefore result in improved learning.

Characteristics of the Learner

Bransford's (1978) second factor is the characteristics of the learner. The characteristics of the learner include the learner's current skills, knowledge, and attitudes.

Domain Knowledge and Aptitude

Domain knowledge appears to affect learning from multimedia. In one study (Mayer & Gallini, 1990), college students read text with and without illustrations that explained the operation of automobile drum brakes. For college students with low prior knowledge of automobile drum brake operation, the illustrations improved their recall of explanative information and their ability to solve problems related to the explanations. For college students with high prior knowledge, the explanative illustrations did not affect their performance. Another study (Kunz, Drewniak, & Schott, 1989) found that for college students with low prior meteorology knowledge, use of pictures in text correlated positively with comprehension. But, for college students with high prior meteorology knowledge, use of pictures in text did not correlate with comprehension.

Studies by Blake (1977) and Wardle (1977, cited in Levie & Lentz, 1982) found that aptitude affected learning from multimedia. In the Blake (1977) study, college students with low or high aptitude in spatial and mental abilities learned the pattern of movement of five chess pieces via moving pictures (film), static pictures, or static pictures with arrows indicating motion. The students with low aptitude performed better in the conditions with moving pictures and static pictures with motion arrows than the condition with static pictures alone. However, the students with high aptitude performed similarly on all three kinds of pictures.

Wardle (1977, cited in Levie & Lentz, 1982) gave 800-word textual passages on various science topics to seventh grade students. Some of the passages included supporting illustrations. During a comprehension test, the students were allowed to look at the materials. Poor readers performed better when the passages included illustrations. For good readers, the illustrations had no effect.

The results of these studies suggest that multimedia is most effective for people with low prior knowledge or aptitude in the domain being learned. This may be because experts already have a mental model and large amounts of information for new knowledge to connect to, but novices do not. Alternatively, novices may not know which information is important and on which information they should focus their attention.

Age

Learner age appears to be an influential factor. Several studies (Ackerman, 1981; Hoffner, Cantor, & Thorson, 1989; Owings & Baumeister, 1979) that presented multiple media to children found that younger children encoded more sensory aspects of stimuli than older children. Older children encoded more semantic information than younger children. It appears that the younger children's processing occurs more at the perceptual level than the semantic level. This deficiency appears to be overcome with increasing experience and maturity.

Another study (Stoneman & Brody, 1983) found that children used multiple media more effectively as the children got older. Children were presented auditory only, visual only, or combined auditory-visual stories that were interspersed with product advertisements. Kindergarten children recognized more advertised products than preschool children. Second-grade children recognized more advertised products than kindergarten or preschool children. Using a cloze test in which every fifth word of a 250-word long textual article was replaced with a blank, Rankin and Culhane (1970) found that adding 17 illustrations (only seven of which were closely related to the text) improved learning for college students but not for sixth grade students. The cloze test measured the ability of the students to accurately replace the missing words and is considered a measure of comprehension.

It appears that the younger children's processing occurred more at the sensory, perceptual level than the semantic level. With increasing experience and maturity, children learned to process information at a deeper (Craik & Lockhart, 1972; Craik & Tulving, 1975), more semantic level and therefore improve their retention of information. Age appears to affect how children processed the multimedia information.

Race and Socioeconomic Status

Race and socioeconomic status appears to affect learning from multimedia. In a study by Rohwer and Harris (1975), low-socioeconomic status black and high-socioeconomic status white fourth grade children learned easy to illustrate prose (e.g., "These monkeys live in banana trees") via audio only, printed text only, picture only, audio with printed text, audio with pictures, printed text with pictures, and audio with printed text and pictures. Overall, children learned better in the audio only condition than in the picture only condition. Children learned better in the printed text only condition than in the picture only condition. Children learned better in the audio with pictures condition than in the audio with printed text condition. However, the low-socioeconomic status black children did better in the combined media conditions (especially audio with pictures) than in the single media conditions while the high-socioeconomic status white children did best in the single media audio alone and printed text alone conditions.

It is possible that the low-socioeconomic children used dual coding advantages, but high-socioeconomic students were able to process semantic aspects of the prose regardless of media presentation technique. This interpretation is consistent with Mayer's (1993) belief that low domain knowledge learners benefit most from multimedia, but high domain knowledge learners have already formed mental models, have large amounts of knowledge in long-term memory available for connecting new information, and therefore learn from simple text. It is also possible that the extra media (such as pictures) were slightly distracting to the high-socioeconomic students.

Learning Activities

Bransford's (1978) third factor is the learning activities. This factor describes what the learner does with the learning materials, and includes attending to the information, rehearsing it, and elaborating it.

Attention

Multimedia can help direct people's attention, resulting in improved learning. For example, one study (Baxter, Quarles, & Kosak, 1978) asked adults in a shopping mall to "look over" a newspaper page that included a story with or without a large photograph. When asked questions about their recall of the newspaper story, people remembered more information when they had seen the story with the photograph than when they had seen the story without the photograph. It appears that the photograph got people's attention and caused them to read the accompanying story.

Similar findings were obtained by a study (Paradowski, 1967) in which people were asked to evaluate the appearance of a book that they were told was about to be published. The book

included text passages that were located beside drawings of bizarre or familiar animals. More incidental learning of the text was found when the text was beside the bizarre drawings. The bizarre drawings appeared to direct the reviewers' attention to the adjacent text.

Work by Tennyson (1978) supports the idea that illustrations can help children learn concepts by focusing attention on key portions of the concepts. Third and fourth grade children learned the concepts of intersection and empty set better when explanatory text included closely related drawings than when the text was accompanied by instructions for the children to create their own drawings. Tennyson suggested that the illustrations helped the children focus on the relevant characteristics of the concepts that were described in the text.

Multimedia can also cause learners to attend to the wrong information, thereby decreasing learning. For example, a review discussed earlier (Park & Hopkins, 1993) concluded that meaningless motion can decrease learning, probably because the motion is distracting.

In a classroom test, Samuels (1967) found that a related picture accompanying a simple short story interfered with poor first grade readers' ability to learn a sight vocabulary. In a laboratory study, Samuels (1967) presented words only or words with identifying pictures to kindergarten children who were learning to read words. When tested using only pictures, the children who saw words with pictures correctly named more words than the children who saw only words. However, when tested using only words, the children who saw words only performed better than the children who saw words with pictures. For this latter test, it appears that the pictures distracted the children. Also, transfer appropriate processing (stimulus encoding matches retrieval test processes) (e.g., Morris, Bransford, & Franks, 1977) or an encoding specificity effect (stimulus encoding matches retrieval cue) (Tulving & Thomson, 1973) appears to have occurred. Learning was best when the test stimuli matched the encoding stimuli. A review of related literature (Samuels, 1970) also concluded that pictures interfered with learning a sight vocabulary for reading.

"Depth" of Processing

As mentioned earlier, several researchers who manipulated the "depth" at which information was processed (Craik & Lockhart, 1972; Craik & Tulving, 1975) found learning improvements. Other researchers found similar results. For example, Sherman (1976) presented text passages to people. For one group of people, each text passage included an ambiguous illustration that showed only part of the scene described in the text. For the other group of people, each text passage included a clear illustration that completely showed what was described in the text passage. The people who got the ambiguous, partially descriptive illustrations recalled more ideas from the text than people who got the clear, completely descriptive illustrations. Sherman believed that the ambiguous, partially descriptive illustrations forced people to process the text more deeply, and learn the text better because people tried to find a match between the text and the illustration.

Bock (1978) presented ambiguous sentences, such as "The soldier likes the port," to college students. The sentences were accompanied by one of two kinds of illustrations. One kind of illustration made the ambiguities in the sentence more obvious. For example, the illustration for "The soldier likes the port" showed a soldier sitting along a harbor ("port") beside a table on which there was a bottle of wine ("port"). The other kind of illustration showed only one of the ambiguities. The illustrations that pointed out both ambiguities led to better free recall of the sentences than illustrations that showed only one of the ambiguities. Bock believed that the illustrations that caused people to notice the sentence ambiguities may have been processed at a greater semantic "depth" than the illustrations that did not cause people to notice the sentence ambiguities. Also, the recognized ambiguities may have caused differential encoding (Madigan, 1969) of the sentences.

Study Time

Time is a learning activity that affects learning from multimedia. One type of "time" is the amount of time the student has to study the multimedia material. A study (Dwyer, 1978) found that when students had a limited amount of time to study illustrations of the anatomy of the heart, line drawings were effective for drawing, identification, terminology, and comprehension tests. But, when study time was unlimited, realistic pictures were effective. Apparently, the extra time allowed students to identify, attend to, and encode the important aspects of the realistic picture.

Criteria Tasks

Bransford's (1978) fourth factor is the criteria tasks, the type of tests used to measure learning. This factor includes recognition, recall, transfer, and problem-solving tests.

Type of Test

Mayer and Anderson (1991, 1992) found that the type of learning test affects learning performance. Mechanically naive college students watched an animation that explained how a bicycle pump works or how automobile drum brakes work. One group heard a verbal explanation before seeing the animation. The other group heard the verbal explanation at the same time as they saw the animation. On a verbal recall test, there were no differences in performance. However, on a creative problem-solving test, the group that heard the explanation with the animation outperformed the group that heard the explanation before seeing the animation.

The researchers believe that their results are consistent with Paivio's (1971, 1986) dual coding hypothesis. In particular, the researchers believe that the synchronous verbal-visual group scored higher on the creative problem-solving test because this test requires use of both representational (e.g., connections between verbal concepts or connections between visual concepts) and referential connections (e.g., connections between verbal and visual concepts), while the verbal recall test requires use of verbal representational connections only.

The previously mentioned work by Dwyer also found that learning was affected by the test of learning. Dwyer (1967, 1978) used text or text with various illustrations to teach heart anatomy to college students. He measured learning using a drawing test, an identification test, a terminology test, and a comprehension test. The drawing tests showed better learning performance for the text with illustrations. However, the comprehension tests showed no difference in learning performance for text or text with illustrations. An explanation for these results is that the drawing test measured spatial information that was best communicated with text and illustrations, but the comprehension test measured heart actions that were best communicated verbally via text alone rather than through static illustrations. Since the students performed best when the test processes were more closely matched with the apparent stimulus encoding, transfer appropriate processing (e.g., Morris, Bransford, & Franks, 1977) appears to have taken place.

Time Between Learning and Test

The time between learning and the test of learning has an effect on multimedia learning. On an immediate test (Palmiter & Elkerton, 1991), people who saw animated demonstrations of user interface procedural tasks were faster and more accurate than people who read text describing the steps. When tested seven days later, the text group was faster and as accurate. In a study by Barrow & Westley (1959), sixth-graders saw a television program or heard an equivalent radio program. On an immediate recall test, the television group did better. However, when tested six weeks later, there were no differences between the two groups. It appears that verbal information is encoded more actively than visual information (cf. Aldrich & Parkin, 1988; Jacoby, Craik, & Begg, 1979; Salomon, 1984). This focused attention may lead to more interconnections with prior knowledge and, hence, better retrieval when tests are delayed.

Baggett and Ehrenfeucht (1983) found that people had good memory for verbal information on an immediate true-false, multiple choice, short answer test, but forgot most of it a week later. However, the researchers found that visual information was retained very well over the course of a week. Visual information may be richer, "bushier," and have more connections available for linking with prior information than verbal information (cf. Baggett, 1984; Bower, 1970; Peeck, 1974; Pezdek & Stevens, 1984; Posner, Nissen, & Klein, 1976).

A review (Levie & Lentz, 1982) of studies (e.g., Bernard, Petersen, & Ally, 1981; Dwyer, 1968; Haring & Fry, 1979; Joseph, 1978; Peeck, 1974; Rusted & Coltheart, 1979) comparing learning with and without supporting illustrations, suggested that illustrations improved recall more in delayed tests than in immediate tests. The recall improvement for people who were tested immediately was about 9%. For delayed tests, the improvement was about 43%. However, the use of some test-retest groups rather than independent groups and the variable, sometimes short, length of the delay makes this conclusion somewhat tenuous. The learning benefits of dual coding may be more obvious at delayed tests than at immediate tests. Immediate recall tests may be easier, more automatic, and require less cognitive processing than delayed recall tests. Delayed recall tests may require more cognitive processing and encourage the learner to take advantage of dual coding associations for retrieval.

Factors that Cross Categories

Finally, there are some factors that touch on more than one of Bransford's (1978) four categories.

Interaction of Medium and Type of Learning

There appears to be an interaction between medium and type of learning with multimedia. Pictures are recognized better than words (Bird & Bennett, 1974; Nelson, Reed, & Walling, 1976; Standing, 1973). Due to greater semantic processing, words may be recalled in a delayed test better than pictures (suggested by Gillund & Shiffrin, 1984; Hoffner, Cantor, & Thorson, 1989; Klatzky, 1980). Perhaps the elements that combine to form the whole picture are encoded more strongly as a group rather than as separate elements. This type of encoding may result in poor recall performance because recall that accesses only a few elements of the picture activates very weak pathways to the memory of the whole picture. However, this type of encoding may produce excellent recognition performance because presentation of the whole picture quickly activates the strong pathway to the unique whole picture memory. So delayed recall activation may be stronger for words than pictures, but recognition activation may be stronger for pictures than words. Alternatively, recognition may involve perceptual memory, so picture recognition is superior to word recognition. Recall may involve semantic memory, so word recall may be superior to picture recall (Hoffner, Cantor, & Thorson, 1989).

Other studies also found an interaction between medium and type of learning. For example, people who received textual instructions were faster on a seven-day delayed procedural task than people who received animated demonstration or combined animated demonstration with spoken text (Palmiter & Elkerton, 1991). Textual presentation of spatial information led to fewer assembly errors than pictorial presentation of spatial information on an assembly task (Bieger & Glock, 1986). To perform the tasks in these two studies, it appears that the students recalled information. Understanding text appears to require more active processing than understanding visual information such as pictures (Baggett & Ehrenfeucht, 1983; Barrow & Westley, 1959; Salomon, 1984). Since text processing requires more attention than picture processing, the learner may build more connections, have more retrieval pathways, and may demonstrate better recall learning for text than for pictures. Also, according to Kozma's theory of learning with media, the textual symbol system may be a closer match with the representation of procedural information in human memory than animations or pictures.

Pictorial presentation of spatial information led to shorter performance times than textual presentation on an assembly task (Bieger & Glock, 1986). College students who used text with

pictures made fewer construction errors on an assembly task than college students who used text only (Stone & Glock, 1981). The students in these studies may have used picture recognition to identify the items for assembly. The picture superiority effect (Nelson, Reed, and Walling, 1976; Paivio, Rogers, & Smythe, 1968) suggests that pictures may be recognized more quickly than words are recalled. This may explain the shorter assembly times in the condition with pictures compared to the condition with text only. Dual coding may explain the assembly accuracy advantage of the picture-text condition compared to the text only condition.

Instructional Design

One of the most influential factors for the effectiveness of multimedia on learning is the quality of instructional design. Good multimedia does not lead to good instruction. Good instruction uses multimedia well. For example, Swezey, Perez, and Allen (1991) used motion to teach people electro-mechanical trouble-shooting skills. The instruction failed to explain critical features or to highlight the importance of specific motion segments. As a result, student learning performance was poor.

Peters and Daiker (1982) obtained similar results using computer-based animation to teach introductory organic chemistry. Students who saw explanatory animations did not show better learning performance on verbal questions than students who saw static illustrations. The researchers believed no performance differences were found because (1) the animations were not closely related to the learning objective for each lesson, and (2) the test questions were verbal, but the instruction was graphical.

To help people learn, educational multimedia needs to be designed in compliance with instructional design principles. Good instructional design principles include the following (Gagne´ & Briggs, 1979; Smith & Ragan, 1992; Mager, 1984):

- Provide instruction only when it is clear that the performance problem is the result of a deficit in knowledge or skills (as opposed to, for example, a physical barrier in the environment, rewards given for opposite behavior, or lack of access to the necessary tools)
- Derive instructional objectives from observing on-the-job performance of recognized role models
- Design instruction so students study and practice only those skills not yet mastered, and only to the level required by the objectives
- Design instruction so students control their progress via their own competence
- Base instruction directly on accomplishing the objectives
- Select and design instructional materials so they impose a minimum number of obstacles between the learners and the learning
- Present instruction using the simplest delivery mechanisms consistent with the objectives, the learners, and the learning environment
- Give students an opportunity to practice each objective and to obtain feedback regarding the quality of their performance and their progress in meeting the objective
- Provide students repeated practice in skills that are used often or are difficult to learn

- Give students immediate feedback regarding the quality of their test performance
- Ensure that desired student performances are followed by consequences the students consider favorable to them
- Within the limits imposed by content and equipment constraints, allow students to sequence and pace their own instruction
- Ensure that the learning environment itself contains the facilities and equipment needed to implement the above principles
- Tell students how to recognize correct and incorrect performance before being allowed to practice the skill to be learned
- Ensure congruence among objectives, learning activities, and assessment
- Measure instruction quality and improve it.

It appears that the instructional design of the multimedia information presentation has a very important influence on the ability to learn the information (e.g., Swezey, Perez, & Allen, 1991; Peters & Daiker, 1982).

Chapter Summary

Many factors affect the ability of multimedia information presentation to help people learn. These factors can be placed in categories that include the nature of the materials, the characteristics of the learner, the learning activities, and the tasks that test learning. Regarding the learning materials, interactivity that requires cognitive processing by the student appears to improve learning (Bosco, 1986; Fletcher, 1989, 1990; Stafford, 1990; Verano, 1987). Motion may be effective when it helps the learner pay attention to and learn information that is related to motion (Park & Hopkins, 1993). Media that encourages deeper, more elaborative processing of information (for example, textual presentation of verbal information versus narrated movie as in Baggett and Ehrenfeucht, 1983 or Salomon, 1984) seems to have a positive affect on learning. Visuals appear to be richer than verbals (Baggett & Ehrenfeucht, 1983; Baggett, 1984; Peeck, 1974). Pictures seem to improve text learning when the pictures closely support the information in the text (Levie & Lentz, 1982). Synchronized presentation of visual-verbal information appears to be better than sequential presentations, possibly because the synchronized presentation helps learners use dual coding to increase interconnections to information already in memory and, for example, to develop device mental models (Baggett, 1984; Baggett & Ehrenfeucht, 1983).

Regarding the learner, multimedia information presentation appears to be more effective for people with low prior knowledge in the domain being learned (e.g., Blake, 1977; Kunz, Drewniak, & Schott, 1989; Mayer & Gallini, 1990; Wardle, 1977, cited in Levie & Lentz, 1982), possibly because experts already have a large number of memories available for interconnecting and organizing new information.

Regarding learning activities, those that encourage the learner to direct attention to important items in the materials (Baxter, Quarles, & Kosak, 1978; Paradowski, 1967; Park & Hopkins, 1993; Tennyson, 1978), to process the information semantically (Bock, 1978; Sherman, 1976), and to spend more time working with the learning materials (Dwyer, 1978) appear to improve learning.

Regarding tests of learning, tests that require cognitive processing that matches the way the information was initially encoded (Dwyer, 1967, 1978; Mayer & Anderson, 1991, 1992; Samuels,

1967) are associated with higher levels of learning, probably due to transfer appropriate processing (e.g., Morris, Bransford, & Franks, 1977) or encoding specificity (Tulving & Thomson, 1973).

Our ability to develop an integrated theory of the effects of multimedia information presentation on learning is hampered by the large number of factors that affect learning from multimedia information and the difficulty of accounting for the two, three and four way interactions of these factors. The theoretical explanations included in this chapter appear to work best in narrowly defined niches, such as Paivio's dual coding explanation for the superior learning found when pictures and text are presented together.

Chapter 4 Most Effective Medium to Present Specific Information

The previous chapter showed that there are reasonable theoretical explanations for the results of some studies examining the effects of multimedia information presentation on learning. The study results can also be used to advance our knowledge of learning in practical, applied settings. To support this goal, the following chapter derives empirically-based recommendations for selecting media to present specific kinds of information. Since current media selection decisions are based on media availability or personal judgments of media effectiveness, these recommendations make a unique and useful contribution to the field of multimedia learning.

Multimedia may improve learning by allowing the instructional designer to use the most effective medium to present specific information. Although media selection models based on learning objectives (e.g., Allen, 1974), data-to-medium rules (e.g., Arens, 1992; Arens, Miller, Shapiro, & Sondheimer, 1988), communication goals (e.g., Elhadad, Seligmann, Feiner, & McKeown, 1989; Feiner & McKeown, 1990, 1991a, 1991b) or learner characteristics, tasks, and instructional settings (e.g., Reiser & Gagne', 1982) are available, these models appear to be based on experienced judgment rather than on empirical studies. To improve the foundation for media allocation decisions, the following section summarizes the limited number of empirical studies that suggest how to allocate specific media for successfully presenting specific kinds of information to be learned. The results are shown in Table 2.

Information to be Learned	Suggested Presentation Media
1. Assembly instructions	Text with supportive pictures
2. Procedural information	Explanatory text with a diagram or animation
3. Problem-solving information	Animation with explanatory verbal narration
4. Recognition information	Pictures
5. Spatial information	Pictures
6. Small amounts of verbal information for a short time	Sound
7. Story details	Video with a soundtrack (or text with supportive illustrations)

Table 2. Empirically-supported suggestions for media allocation.

1. Assembly Instructions

To learn assembly instructions, it appears that text and pictures work well. Studies described earlier (Bieger & Glock, 1986; Stone & Glock, 1981) found that people performed an assembly task quicker when they received spatial information via pictures, but assembled with fewer errors when they received spatial information via text.

2. Procedural Information

To present procedures for operating a device, it appears that using a diagram and explanatory text helps people acquire a mental model of how the device works. This device model allows people to infer procedures more quickly than people who learn about the device by using routine or repetition without full comprehension. Kieras and Bovair (Kieras, 1984; Kieras & Bovair, 1983, 1984) created a simple device consisting of two buttons, one switch, one selector dial, and four indicator lights. One group learned the procedures "by rote." The other group was given a diagram and explanatory text that helped the group members develop a mental model of how the device worked, then they were given the same procedure training by rote. The diagram and explanatory text included an overall explanation of the device (control panel for the phaser bank of the Star Trek Starship Enterprise), a description of the major components in the diagram, and a description of how the major components were related to one another (how a change in one component affected another component). Neither group received any procedural information. The group who got the diagram and explanatory text as well as rote instruction learned the procedures faster and more

accurately, performed the procedures faster, and developed new, more efficient procedures more often than the group who got only rote instruction.

The researchers believed the key to success was the ability of the diagram and text group to help learners develop a mental model of the device's operation so that procedures could be inferred. A follow-up experiment confirmed that this group's success was due to the explanations of how the components related to one another rather than the motivational aspects of the association with Star Trek, the description of power flow and how items were connected, or general design principles and rationale such as why a particular item was needed.

Another study (Palmiter & Elkerton, 1991), suggests that text is better than animation for presenting procedural information. People who saw animated demonstrations learned HyperCard authoring procedures faster and more accurately than people who saw only text. However, seven days later the people who saw only text were faster and as accurate as the people who saw animated demonstrations.

3. Problem-Solving Information

To learn problem-solving information, an animation with verbal narration has been shown to be effective (Mayer & Anderson, 1991, 1992). People who saw an animation with verbal narration did better on a bicycle pump problem-solving test than people who got no training, saw the animation only, or heard the verbal description only.

To perform mathematical problem-solving, graphical presentations of information can improve performance compared to textual presentations (Moyer, Sowder, Threadgill-Sowder, & Moyer, 1984; Reed, 1985; Threadgill-Sowder & Sowder, 1982; Threadgill-Sowder, Sowder, Moyer, & Moyer, 1985). For example, one study (Threadgill-Sowder, Sowder, Moyer, & Moyer, 1985) found that grade school students who scored in the lowest quartile on a cognitive restructuring test (Hidden Figures Test) were able to improve their scores when the story problems in the test were presented using drawings that organized the problem data. Another study (Moyer, Sowder, Threadgill-Sowder, & Moyer, 1984) found that children in grades three to 11 solved mathematical word problems better with text combined with illustrations of the problem elements than text alone. The illustrations were more helpful to the low-ability readers than the readers with more ability. It appears the illustrations helped make the word problems more concrete, easier to understand, and, therefore, easier to solve.

4. Recognition Information

To communicate information that people need to recognize, pictures are extremely effective. One study (Nickerson, 1968) found that people had 63% recognition accuracy for a group of 200 black and white photographs one year after initial viewing. In another study (Shepard, 1967) people looked at 600 pictures, sentences, or words. In an immediate test, recognition accuracy was 98% for pictures, 90% for sentences, and 88% for words. Another study (Standing, Conezio, & Haber, 1970) showed people 2,560 photographs for 10 seconds each. After three days, participants recorded recognition accuracy of over 90%. Read and Barnsley (1977) showed adults pictures and text from the elementary school books they used 20 to 30 years ago. Recognition accuracy rates for pictures and text were better than chance, with pictures alone being recognized more accurately than text alone. Finally, Stoneman & Brody (1983) found that children in visual or audiovisual conditions recognized more products in commercials than children in an auditory only condition.

5. Spatial Information

Bartram (1980) arranged for college students to learn how to get from a starting point to a destination using a minimum number of buses. The bus route information was presented via maps or lists. The students were asked to provide as quickly as possible the correct list of bus numbers in the correct order. If the students made a mistake, they were asked to continue working.

Bartram measured the time it took to correctly complete each bus route task. The study found that the students learned the bus route information more quickly when they used a map than when they used lists. The researcher believed that the students performed a spatial task, and the maps were superior to lists because the map presentation of information is consistent with people's preferred internal representation of spatial information.

In an exploratory study, Bell and Johnson (1992) allowed four people to select pictures or text for communicating instructions for loading a battery into a camera. Qualitative results showed a strong preference for pictures rather than text. The researchers believed that the information to be communicated was spatial, and that the results supported the hypothesis that spatial information should be presented pictorially.

Garrison's (1978) study supported the idea that spatial relations are recalled and recognized better by children when the spatial relations are presented via story text and illustrations rather than story text alone. A series of studies by Dwyer (1967, 1978) found that illustrated text was better than text alone when students were tested on spatial information using a drawing test. After reviewing Dwyer's work, Levie and Lentz (1982, p. 213) concluded that, "on the whole, the degree to which an educational objective is aided by pictures depends on the emphasis given to knowledge about spatial information in the test of learning."

6. Small Amounts of Verbal Information

Sound appears to be an effective way to communicate a small amount of verbal information for a short period of time. For example, Murdock (1968) found that recognition for items in a nine item verbal list was better with an auditory than a visual presentation. Another study (Watkins & Watkins, 1980) found that echoic memory causes better short-term memory for a few verbal items when the items are presented via auditory rather than visual mode. A review of the related literature (Penney, 1975) concluded that, for tasks involving short-term memory, auditory presentation is better than visual presentation. This conclusion appears to be appropriate for about six verbal items.

7. Story Details

For recalling story details, video with a soundtrack appears to be effective. Baggett (1979) found that, after a seven day delay, people who saw a dialogueless movie made fewer errors when recalling the story structure than people who heard equivalent text. On an immediate test of factual recall, children who saw a movie with an audio narration did better than children who heard a similar narration via radio (Barrow & Westley, 1959). Children recalled more story details when the story was presented via television with a narrated soundtrack than radio (soundtrack alone) (Beagles-Roos & Gat, 1983). Another study (Meringoff, 1980) found that children remembered more story actions when they saw a televised film with story narration than when they were read a very similar illustrated story.

Static pictures also appear to help children learn auditory, oral prose. Levin and Lesgold (1978) reviewed a dozen studies that examined the effect of pictures on children's ability to learn auditory, oral, fictional, stories. The pictures reflected the contents of the stories and learning was measured by short answers to factual questions. The reviewers found that related pictures improved learning of the oral prose.

A review of the literature on printed text and illustrations (Levie & Lentz, 1982) found that about one-third more information was learned by children when textual information was shown in accompanying illustrations than when there were no illustrations. Learning was generally measured on immediate, multiple choice, recognition tests.

The learning advantage found when verbal and illustrated information are presented together appears to be due to the dual coded integration of the information rather than due to repetition of the

information. Levin, Bender, and Lesgold (1976) presented to children (1) one oral sentence at a time, (2) the same sentence twice in succession, or (3) the sentence with a related illustration. A cued-recall test using short questions about the stories formed by the sentences found that learning was best with the sentence-illustration combination rather than the repeated sentences. The absence of a learning advantage for repeated sentences is consistent with Greeno's (1964) finding that learning of paired-associates (e.g., "BREAD—2") was usually no better for massed, repeated item presentations than for distributed, single presentations of items.

Paivio and Csapo (1973) presented words and pictures in a random sequence that included presenting (1) a word twice, (2) a pictorial representation of the word twice, or (3) the word once and the picture once. A free recall test found that learning was best when the word and picture were each presented once.

The results of the Levin, Bender, and Lesgold (1976) and Paivio and Csapo (1973) studies suggest that dual coding, rather than repetition, is responsible for the improvements in recall of verbal-illustration combinations.

Finally, to help instructional designers use illustrations to effectively communicate textual information, Levin (1981b; Levin, Anglin, & Carney, 1987) identified text-learning functions that illustrations can perform and how the illustrations should be designed and used. The five functions are (1) Decoration—Illustrations that are not related to the text, but serve to make the text more attractive, (2) Representation—Illustrations that are closely related to the text, (3) Organization—Illustrations, such as maps and diagrams, that arrange the text to make it more coherent, (4) Interpretation—Illustrations that clarify unfamiliar, difficult concepts such as the mechanics of blood pressure, and (5) Transformation—Very unusual illustrations that use associative mnemonic techniques to make critical information easier to understand by "(a) recoding it into a more concrete and memorable form, (b) relating in a well-organized context the separate pieces of that information, and (c) providing the student with a systematic means of retrieving the critical information when later asked for it" (Levin, Anglin, & Carney, 1987, p. 61). These illustrations appear to be the basis of the four types of illustrations (Decorative, Representational, Organizational, Explanative) in Mayer's (1993) framework for research on learning from text and pictures which was discussed earlier.

Chapter Summary

Multimedia appears to be an effective way to learn when the multimedia presents information in a way that is compatible with people's preferred internal representation of that information (Kozma, 1991). For example, Bartram's (1980) study found that maps were better than lists when learning spatial bus route information. This idea is consistent with the more general concept of display-control or stimulus-response compatibility (Fitts & Seeger, 1953).

It appears that certain media combinations are better than others for communicating specific kinds of information. Text and pictures seem to help people learn assembly information (Bieger & Glock, 1986; Stone & Glock, 1981). Diagrams and explanatory text support the creation of device mental models for learning system procedures (Kieras, 1984; Kieras & Bovair, 1983; Kieras & Bovair, 1984). Pictures are extremely effective for recognition tasks (Nickerson, 1968; Shepard, 1967; Standing, Conezio, & Haber, 1970; Stoneman & Brody, 1983). Illustrations appear to be most helpful for communicating spatial information (Bartram, 1980; Garrison, 1978). Sound seems to be the best medium for communicating a small amount of verbal information for a short period of time (Murdock, 1968; Penney, 1975; Watkins & Watkins, 1980). Video with a soundtrack communicates story details very well (Baggett, 1979; Barrow & Westley, 1959; Beagles-Roos & Gat, 1983; Meringoff, 1980). Text with supportive illustrations helps people learn verbal information (Levie & Lentz, 1982; Levin, Bender, & Lesgold, 1976; Levin & Lesgold, 1978).

Chapter 5 Conclusions

The effects of multimedia information presentation on learning are very complex. It is clear that the learning materials, learner, learning activities, and learning tests have very strong, simultaneous effects on learning. Due to the simultaneous interaction of these factors, it is unlikely that a single, overarching, unifying theory of multimedia and learning will be developed. However, there are some areas of multimedia learning that appear to have reasonable theoretical explanations.

- Paivio's dual coding theory (Paivio, 1971, 1991; Clark & Paivio, 1991) is a good explanation for learning when verbal and related pictorial media are presented together. A review that included early studies on audio-visual information presentation for learning (Spencer, 1988) reached the same conclusion.
- Baggett's bushiness hypothesis (Baggett, 1984, 1989; Baggett & Ehrenfeucht, 1982; 1983) explains some of the learning success when more salient media, such as pictures, are used with less salient media, such as auditory words (e.g., Baggett, 1984).
- Encoding specificity (Tulving & Thomson, 1973) explains the beneficial effect of presenting the same media when learning and testing (e.g., Dwyer, 1967, 1978; Samuels, 1967).
- Mayer's theory of explanative illustrations supports the finding that media need to serve an explanatory, rather than a decorative, purpose (e.g., Mayer, 1993; Levie & Lentz, 1982).

Although the general theories by Kozma (1991) and Baggett (1989; Baggett & Ehrenfeucht, 1982) are a good start, more complete predictive theories of multimedia learning need to be developed and validated to move this field forward. We need to know when multimedia information presentation will be helpful and why.

For multimedia instruction to have a significant, positive impact on education, we need to make multimedia instructional design decisions based on empirical studies such as the ones described in this review. Media selection charts, such as the ones by Allen (1974) or Reiser and Gagne' (1982), which are based on the judgment of experienced instructors, are helpful, but improvements in multimedia instructional design should be based on converging trends from well-controlled, unbiased, and repeatable empirical studies. The media will continue to evolve, but, presumably, human cognitive processing will remain the same. We should focus our research efforts on understanding how people process multimedia information rather than on how multimedia technologies compare to one another on measures that are independent of organizing theories.

Some studies that will help to move forward the field of multimedia information presentation and learning include the following:

- To determine whether time on task is an alternative explanation for learning performance differences in traditional classroom lectures compared to computerized multimedia information presentation, provide learners the same amount of time to learn the same information in the two techniques. This way, time on task and learning information are kept relatively constant. Learning performance differences may be due to differences in information presentation. Since student attitudes appear to be affected by multimedia information presentation, also measure student attitudes to determine whether students prefer the multimedia learning technique over the traditional classroom lecture.

- Determine whether learners' positive attitudes toward multimedia learning materials translate into additional time on task, and improved learning, in free learning situations. For example, compare time on task and learning when information is presented on a computer using "monomedia" (such as only text) versus the same information presented on a computer using multimedia. The information is about the same, but the multimedia may be more stimulating. Use the computer to measure each learner's time on task and use on-line textual questions to measure retention of the learned information.
- Mayer (1993) believes that the four following cognitive conditions are necessary for illustrations to be effective: (1) the text explains how the system works (rather than simply listing system components), (2) the illustration summarizes key system components, component states, and the relationships of component states between components (allowing the learner to create a cause-effect chain), (3) the learners have low domain knowledge (because the explanative text and illustrations are more helpful for building an appropriate mental model; high domain knowledge learners can build a mental model from text alone), and (4) the performance tests are appropriate for the type of illustration being studied (for example, if the illustration is explanative, don't test for number of facts recalled; instead test for problem-solving transfer). Validate Mayer's suggestions for necessary cognitive conditions for illustrations to be effective by performing studies that explicitly manipulate the variables he believes are important. For example, compare learning from illustrations that are accompanied by explanative versus descriptive text, text that describes component relationships versus text that does not, using high versus low domain knowledge learners, or tests that match or do not match the illustration used.
- Extend Mayer's (1993) theory of explanative illustrations (listed above) to explanative video. This study will determine whether the same theory can be applied to a different medium.
- Validate Park and Hopkins (1993) six general recommendations for when to use motion to improve learning. These recommendations are: (1) to demonstrate sequential actions in a procedural task, (2) to simulate causal models of complex system behaviors, (3) to show otherwise invisible system functions and behaviors, (4) to show a task that is hard to describe verbally, (5) to provide a visually motional cue, analogy, or guidance, and (6) to focus attention on specific tasks or displays.
- Although there is no question that pictures are generally recognized better than words at immediate and delayed tests (cf. Shepard, 1967), the results for immediate and delayed recall tests are less clear. For immediate tests, the results of studies by Paivio (1975) and Smith and Magee (1980) suggest that pictures are recalled better than words. For delayed tests, due to an increased emphasis on semantic processing, Gillund and Shiffrin (1984), Hoffner, Cantor, and Thorson (1989), and Klatzky (1980) suggest that words will be recalled better than pictures. However, Peeck (1974; 1983, cited in Peeck, 1987; 1985, cited in Peeck, 1987; 1987; 1989) believes that as the delay of a retention test increases, learner's increasingly emphasize information from pictures rather than text. Levie and Lentz (1982) found that pictures seemed to facilitate learning more in delayed tests than immediate tests. To help resolve these inconsistencies, perform a recall test using concrete words (e.g., "chair") and simple pictures that can be named with concrete words (e.g., a picture of a balloon). Show each kind of stimulus for the same amount of time, do not encourage any special semantic processing such as categorization or naming, then perform immediate and delayed recall tests with two different groups of people exposed to the same stimuli.

- Perform studies to better determine why redundant media sometimes help people learn and sometimes does not. Earlier the author identified the following effects as possible explanations for these results—conceptual processing, attention, media salience, dual coding, and differential encoding. Take at least one of these possible explanations and examine it in greater detail. For example, to examine the effectiveness of dual coding as an explanation, create conditions in which one group of people sees a sequence of computer screens showing text with pictures of concrete words (e.g., "balloon" with a picture of a balloon), one group sees each text item twice on a screen (e.g., "balloon" "balloon"), and another group sees each picture twice on a computer screen. Perform a free recall test. If dual coding is taking place, then recall should be highest for the situation in which the participants saw text with pictures.
- Alternatively, to confirm that multimedia information presentation improves learning due to dual verbal-pictorial associations rather than repeated presentations of verbal information alone or pictorial presentations alone, perform a study which redundantly presents the same verbal information via various media (e.g., text, auditory, touch via raised letters) and compare it to learning via combined verbal-pictorial media (e.g., text and picture). If the information is verbal, it should not matter how many senses are involved with receiving it (cf. Nugent, 1982). Learning should be best with the verbal-pictorial combination.
- To find out whether the media or the kind of processing is responsible for learning from media, present information in one way, then induce differential processing by adding other tasks. For example, present pictures, then ask one group of participants to describe the pictorial information verbally (this task encourages pictorial and verbal processing). Compare performance to a group that did not have the verbal description task. Dual coding theory is supported if learning is better in the pictorial media-verbal description condition compared to the pictorial media only condition. For dual coding, related work has already been performed (e.g., Paivio & Csapo, 1973; Paivio & Foth, 1970). For depth of processing, this concept can also be applied to semantic versus syntactic versus physical processing.
- With text, the learner can slow the pace of presentation and re-read confusing segments. However, when verbal information is presented via sound, the learner usually cannot control the pace of presentation or rewind the sound. Perform studies to determine at what speed auditory verbal information should be presented to maximize its comprehension. Also determine whether this speed depends on the learner's prior knowledge of the domain and the complexity of the information. Theory suggests that learner's with high prior domain knowledge will understand the information more quickly and can comprehend verbal auditory information that is being presented at a faster rate than low prior knowledge learners. Since readers appear to benefit from the ability to re-read information, examine whether learners benefit from an auditory re-wind capability.

The chief contributions of this paper are that it integrated results from a wide variety of disciplines and it developed media allocation recommendations based on empirical research. The author hopes that this paper will serve as a starting point for other researchers to perform studies to improve the use of multimedia information presentation to aid learning.

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Biography

Larry Najjar attended the College of the Holy Cross in Worcester, Massachusetts. He graduated with a BS in psychology in 1980. In 1983, he was awarded an MS in engineering psychology from the Georgia Institute of Technology in Atlanta, Georgia.

After graduating, Larry worked for Systems Research Laboratories in Hanover, Maryland. He designed the software and hardware user-interface for an advanced word processing and audio transcription work station. In 1984, he joined the IBM Corporation in Rockville, Maryland. Larry helped design the user-interface for the next-generation US air traffic control system, including the digital flight strips, keyboard, work station, and user warnings. In 1989, he transferred to Atlanta, Georgia, where he designed and tested user-interfaces for a wide variety of commercial applications.

Larry left IBM in 1993 to pursue his PhD in engineering psychology at the Georgia Institute of Technology. He is currently a graduate research assistant at the Georgia Tech Research Institute. He performs task and function analyses, helps conduct studies, writes training materials, prototypes user-interfaces, and writes on-line help. For his dissertation, Larry plans to examine the effects of multimedia user-interface design on learning.