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ABSTRACT

This paper reviews the literature pertinent to learning with graphics. The dual coding theory provides explanation about how graphics are stored and precessed in semantic memory. The level of processing theory suggests how graphics can be employed in learning to encourage deeper processing. In addition to dual coding theory and level of processing theory, the area of motivation and attention is also reviewed to show how graphics and emotion are related and how graphics should be designed to communicate desired intent. It is noted that appropriate design decisions about the use of graphics are often based on knowledge from cognitive science and that current research in graphics design related to this topic is inadequate. The area of cognitive science is incorporated into instructional technology so that the effectiveness of graphics in assisting can be optimized. (Contains 48 references.) (Author/MES)

A Theoretical analysis of Learning with Graphics - Implications for Computer Graphics Design

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Abstract :

The purpose of this paper is to review literature pertinent to learning with graphics. The dual coding theory provides explanation about how graphics are stored and processed in semantic memory. The level of processing theory suggests how graphics can be employed in learning to encourage deeper processing. In addition to dual coding theory and level of processing theory, the area of motivation and attention will also be reviewed in this paper to show how graphics and emotion are related and how graphics should be designed to communicate desired intent. As noted, appropriate design decisions about the use of graphics are often based on knowledge from cognitive science. However, current research in graphics design related to this topic is inadequate. This article attempts to incorporate the area of cognitive science into instructional technology so that the effectiveness of graphics in assisting can be optimized.

A Theoretical analysis of Visual Learning - Implications for Computer Graphics Design

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Gagnè, Briggs, & Wager (1992) suggested that the instruction should be designed not only to incorporate the principles of behaviorism but should also consider how information is processed in memory. To employ graphics in the design of computer assisted instruction, it is necessary to understand how graphics are cognitively processed. Although the effects of graphics have not been extensively studied and researched in computer assisted instruction, graphics have been frequently used in the design of various instructional materials and media for communication.

The use of graphics in communication has had a long history. Through art and technology, human beings have been engaged in reconstructing their perceptual world for thousands of years (Bolter, 1991). Ever since human beings learned to communicate, symbols have been created and used to communicate. Pictographic language evolved in some cultures, such as Chinese and Egyptian. For example, the Chinese character was a graphic symbol depicting an object or event by the people within a homogeneous culture group, certain pictorial or verbal information gives rise to similar interpretations of a specific reality or message (Pettersson, 1989).

Like communication through verbal language, the use of graphics relies on the recall of a visual memory (Mealing & Yazdani, 1990). Pictures can communicate more than just their surface contents because a wide range of prior knowledge and experience is brought to bear on the imagery by the viewers, and at the same time, this can be exploited to enrich the meaning of an graphic. Although computer technology does not have a long history, computer graphics, animation, and various visual effects have been widely incorporated in instructional design. Much instructional design is based on designer's intuition about what should be done. In this paper, some of the theories that related with the use of graphics will be discussed. The dual coding theory discusses the natural of semantic memory. The level of processing focuses on the processes learners employed in encoding with graphics. Motivation and attention suggest the emotional factors related with the process of deciphering and encoding of given information. In addition, the implications for graphics design are discussed.

Coding Systems

The best support for the merits of graphics comes from dual coding theory (Paivio, 1971; 1983; 1986; 1990; 1991). The primary focus of dual coding theory concerns the nature of semantic representation in memory. According to Paivio, there are two functionally distinguishable symbolic systems in semantic memory - one verbal and the other non-verbal. Dual-coding theory suggests that when information is dual-coded, it is easier to retain in memory. The important points emphasized in this theory are that the verbal and non-verbal systems can be activated independently and that there are interconnections between the systems that allows dual codes. It is assumed that concrete information can be stored in either non-verbal image system, verbal system, or both systems.

The two systems have different organizational and processing characteristics. The basic units in the verbal system are termed *logogens*, and the basic units in the non-verbal systems are termed imagens. Sadoski, Paivio, & Goetz (1991) compared the structures of the two systems. They described that information in the verbal system is organized with a sequential or hierarchical structure; while non-verbal information is organized within a nested set of structure (see Figure 1). In Figure 1, the structures of verbal system and non-verbal system are contrasted in the example. In the verbal system, an eyeball would be described by arranging information into words and sentences, an eye would be described through the formation of paragraphs, and the descriptions of an entire face might compose a chapter. Unlike the verbal system, the non-verbal system is not structured sequentially . For example, eyes, nose , and mouth are perceived separately, but are parts of a face. Even the eye is a nested set, having an eyelid, and an eyeball.

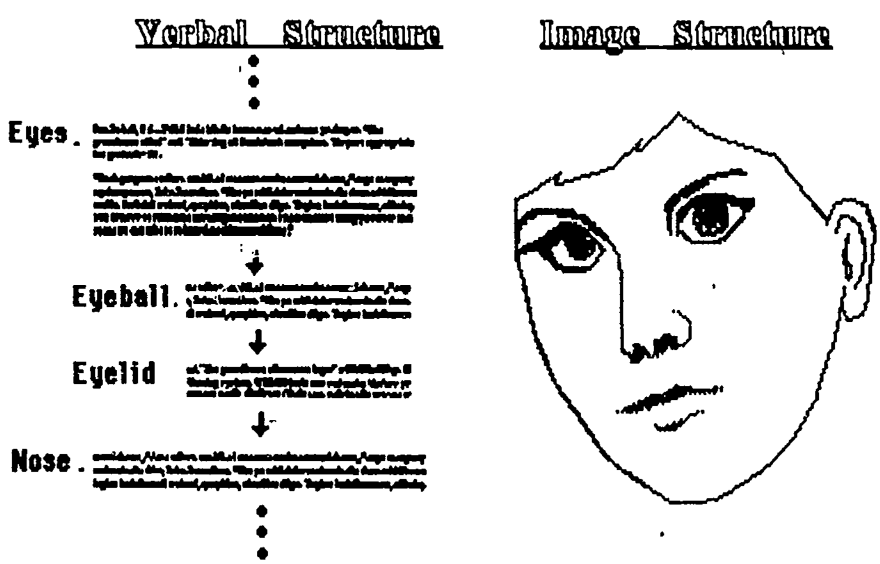

Figure 1. Example of Contrasting Verbal and Non-Verbal Systems in Dual Coding

Dual coding theory distinguishes three different levels of processing: representational processing, referential processing, and associative processing. Representational processing refers to the activation of logogens by verbal stimuli and imagens by nonverbal stimuli. For example, the word "dog" activate the corresponding logogen, and the picture of a dog activate corresponding imagen. Associative processing refers to intra-system (within image or verbal system) connections. In other words, words or phrases are associated with other words or phrases. For example, the phrase "once upon a time" may activate the word "prince" or "princess". The phrase "once upon a time" may activate other language units based on people's experience. Referential processing refers to the inter-system (cross system) activation. For example, language can evoke image, and imagery can evoke language as well.

According to Paivio, all cognitive tasks require representational processing and some may involve all three levels of processing. In other words, when viewing the word "apple", under the representational processing, the corresponding descriptions (logogens) which directly associated with fruit apple will be activated. Under associative processing, the fruit orange might be activated because apple and orange are under the same class fruit. However, if a person is working extensively with an Apple computer, at associative processing level, the description associated with an Apple computer might be activated under appropriate contextual conditions. At referential processing level, an image of apple or an image of an Apple computer will be activated by the descriptions of an apple or an Apple computer. A notation might be used as followed to express the above descriptions about the three levels of processing: apple -> representational processing-> descriptions of apple -> associative processing -> descriptions of an orange or an Apple computer (based on the context) -> referential processing -> an image of an orange or an image of an Apple computer.

Either verbal or visual information can trigger activity in any of three levels of processing within or cross systems. The verbal system and non-verbal system are bi-directionally interconnected, and the interconnection is assumed to be one-to-many, rather than one-to-one. For example, a given picture can evoke any of a number of verbal or image information, or descriptions corresponding to different exemplars of a referent class. Precisely which images or descriptions will be activated at any moment depends on the context of the stimuli, and how those stimuli interact with viewer's experiences and expectations.

Paivio postulated that pictures were easier to remember than words due to "the mnemonic superiority of the image code over the verbal code" (Paivio, 1991, pp 265). Although it is assumed that pictures and words activate independent imaginal and verbal codes, the availability of this dual code differs. That is, a verbal code for a picture is more available than an imaginal code for a word. As stated, pictures were better remembered than words because pictures were more likely to be redundantly (additively) encoded. There is evidence to support this assumption. For example, Paivio and Csapo (1973) investigated the relative merits of imaginal and verbal codes using an incidental recall task in which the orienting task was given to control the way items are coded during input. The results indicated that higher recall test scores were obtained in imaginal codes. In another study, Paivio (1975) also concluded from a repetition-lag experiments that verbal and non-verbal memory codes are statistically independent and additive in their effect on free recall, however, the non-verbal is mnemonically stronger than the verbal codes. Other studies such as Paivio & Lambert (1981), Roediger & Weldon (1987), and Weldon & Roediger (1987) also had the similar findings.

In addition to addressing issues of encoding, Paivio (1991) provided guidelines for maximizing retrieval of specific content that has been learned. As suggested, effective retrieval cues activate the representations created at encoding. If the information is coded with verbal or pictorial cues, more correct recall would occur when encoding cues are used in retrieval task. Picture superiority effect can be reversed by changing retrieval demands (see also Roediger & Weldon, 1987; Weldon & Roediger, 1987). This proposition is similar to Tulving's encoding specificity theory of retrieval (1983).

Although there are criticisms of the dual coding theory (Paivio, 1991; Kobayshi, 1986), the dual coding theory is to date the dominant theory that directly addresses the role of images in cognition. Because the semantic interconnections between verbal system and image system are assumed to be one-to-many, rather than one-to-one, in both directions. It is worth noticing that a given picture can evoke any of a number of verbal (or image) information or descriptions corresponding to different exemplars of a referent class. In order to design effective graphic materials, the characteristics and experiences of learners in processing the cues should be well understood, and the use of pictorial cues in retrieving is also need to be consistent with the cues used at encoding.

Coding Processes

Another theory that supports the need for the use of pictures in learning and memory is "Level of Processing" theory (Craik & Lockhart, 1972). As noted by Paivio (1991), the superior recall effects of the dual coding of to-be-remembered information might be explained by levels of processing (or elaborative processing). According to level of processing theory, the deeper the information is processed, the longer it will be retained in memory. In other words, if the information to be remembered is rehearsed with specific mnemonic strategy or cueing materials, it can retain longer in memory.

To provide opportunities for deep processing (or elaborative processing), the use of imagery instruction can be used to encourage the deep processing by learners of to-be-learned materials. For example, in the area of reading instruction for children, imagery instruction has been widely used as a rehearsal strategy for remembering what was read. In Figure 2, the Mother Goose's rhyme on the left can be presented to children. The children can be asked to imagine a picture about the story, or they can draw a picture about the story in order to help them remember the rhyme and the story. Although imagery instructions facilitate memory of to-be-learned materials, a lot of training and practicing is often required (Pressley, 1977; Alesandrini, 1982; Pressley, Cariglia-Bull, Deane & Schneider, 1987). The difficulties in carrying out imagery instruction might overtax children's functional memory limitations, and it was concluded that using imagery often does not facilitate young children's verbal learning (Pressley & Levin, 1977, 1978). As noted by Pressley, Cariglia-Bull & Deane (1987), the effectiveness of imagery instruction is related with individuals' intellectual competence, their memory capacity and experience with the strategy. In regard to learning of new concept, the imagery instruction might not be successful because we cannot expect people to form mental images of concepts not yet known, especially when a complex science concept or math concept are involved. In order to use an imagery strategy successfully, appropriate training and instruction are required. The imagery instruction might be varied for different group of learners or different individuals due to differences in their memory capability.

In contrast to generating images internally by learners for rehearsing the learning content as mentioned above, providing pictures externally from

There was an old woman tossed in a
basket
Seventeen times as high as the moon;
For under her arm she carried a
broom.
Old woman, old woman, said I!
Whither, oh whither, oh whither so
high?
To sweep the cobwebs from the sky,
And I'll be with you by and by.

Figure 2. Mother Goose's Nursery Rhyme - There was an old woman tossed in a basket

instruction contributes substantial merit to help learners visualize the concepts to be learned (Mayer & Anderson, 1992; Rieber, 1994). Pictures have been commonly used to help learning within different content areas. When presented with the reading material, pictures facilitated children's retention and recall of the reading materials (Goldstein & Underwood, 1981; Haring & Fry, 1979; Levie & Lentz, 1982). Graphics provide more cues to allow deeper processing of information in their memory. For example, in Figure 2, the graphics on the right allows children to compare every detail in the picture with the words or sentences in the rhyme so that the story and the rhyme can be remembered through rehearsing with these cues.

In studying the effect of graphics in learning science instruction, Reid, Briggs & Beveridge (1983) found significant improvement in post-test scores among subjects when pictures are presented. As observed, due to the increased attention among individuals toward the materials, learners are motivated to compare more carefully the information available in pictures and written prose. This rehearsing or elaborative process leads to the development of more effective semantic storage networks so that the information can be easily retrieved later. It might be possible to describe this effect in terms of Craik & Lockhart's level of processing (1972) of the given information and hence facilitate recall. .

Although level of processing theory argues deep process and elaborative process encourages better recall, it emphasizes on semantic level, rather than sensor level of processing. According to level of processing view, memory traces are "by-products" of the perceptual processing (Kobayshi, 1986). The perceptual processing involves analysis from incoming stimuli from meaningful information. In other words, viewers tend to associate given pictures with text based on their own interpretation of which provides meaningfulness to them. Under this argument, it is worthwhile to notice whether the pictures provide necessary connections for learners to associate between what they are familiar with and what they need to learn or remember. In figure 2, when reading the rhymes with the pictures, learners might tend to relate each sentence either with the whole picture or with specific portion of the picture. They might look for the cues in the pictures to help them construct the meaning described in the rhyme so that the materials can be easily processed and coded in their memory. For example, when they read the word "cobweb", they might look for the clue in the picture. When they are not able to find a real "cobwebs", they might interpret the cobweb-like star rays to what has been referred in the story.

The level of processing theory provides an explanation of the process in learning with graphical information. Individual differences, which presumably reflect innate factors and the experiences of the individual, influence the activation of representations and the effect of specific stimulus attributes. These are all important considerations for graphic design. Understanding the characteristics of the learners and how learners associate between the text and pictures is essential.

Motivation and Attention

In the real world, emotion is closely related to the process of learning (Zajonc, 1980). Emotion affects how information is attended, stored and retrieved (Langhinrichsen & Tucker, 1990; Lehmann & Koukkou,1990). Since perceiving information involves cognitively selecting and filtering the elements from given stimuli (Pettersson, 1989), the learners' interests and expectations play an important role in extracting information and reconstructing their understanding.

The emotional states of learners is considered an important variable in determining the effectiveness of learning information. Motivation refers to arousal and goal-oriental aspects of behavior that company the verbal or nonverbal memory system, and affective reactions would ordinarily occur more quickly to pictures than to words (Paivio, 1986; 1990).

Rogers (1983) considers emotion as a third code of cognition in addition to verbal codes and imagery codes. He reveals that how people feel is related with how people can learn and remember from given information. What makes a piece of information fit into cognition is largely a matter of coherence of one's belief and desire. Implied from Rogers' interpretation, the emotional effects that graphics can provide is highly related to how given pictures are processed and how they interact with learners' internal mental states. As proposed, affective reaction to the graphic information is part of the encoding process in cognitive system (Roger, 1983). He assumed that when affective response is activated, retention is enhanced.

The positive attitude toward the learning materials motivates learners actively operate and organize the given representations into their own construction.

When related with what learners like and what make them curious to see, pictures might create considerable learning interest that motivate them to learn the information described in the text (Samuels, 1970). When individuls are interested, it is more likely that they will devote their effort in learning tasks (Keller, 1983; Visser & Keller, 1990). Although how computer graphics motivate students to learn has not been actually explored and measured from empirical studies, a lot of empirical studies (Levie & Lentz, 1982; Mayer, 1989; Mayer & Anderson, 1992; Mayer & Gallini, 1990; Rieber, 1990; Swell & Moore, 1980) have addressed the emotional impact on learning. The finding suggests that pictures enhance readers' enjoyment, and help children develop positive attitudes toward reading and make the task of learning to read more pleasant. When involvement is enhanced, it becomes easier for students to benefit from the reading materials and acquire concepts they need to know from the verbal materials.

Given that affective reactions would ordinarily occur more quickly to pictures than to words (Paivio, 1990), more precautions and considerations should be taken in relating what is perceived by learners and what is desired to be perceived from the intended objective. Fitzgerald (1989) argued that the use of pictures needs to more attend to the properties in the pictures relevant to establish intended belief and desires from learners. Due to different people have different experiences with graphics, when a picture is used to communicate, considerations should be taken regarding whether the picture is appropriate to learners' experiences. For example , the use of red color might create warm feeling. It might also be interpreted as a "warning" or "wrong response" by viewers. The design decision about integrating specific graphic attributes, such as color, format, or animation, depends not only on "which" attribute to choose to interact with learners but also "how" to use it properly and "when" to use it to meet intended purposes.

Implications from Graphic Research

Psychologically, pictures provide distinct features in presenting intended information and facilitate certain emotional reactions. As noted by Salomon (1979), pictures can communicate better only when the symbolic codes they use are closer to, or more congruent with what receivers have experienced or what ought to generate for concept construction. In order to use graphic materials to help students learn, one should be able to incorporate graphics related to the concepts or knowledge they have learned and they are going to learn .

The instructional justifications of using visualization in various intended purposes including increasing learning interest, motivation, curiosity; presenting opportunities for learner to perceive intended context; spanning linguistic barriers; fostering generalization of responses to new situations; providing greater flexibility in the organization of instruction; illustrating, clarifying, and reinforcing oral and printed communication, and sharpening powers of observation (Dwyer, 1985). However, graphics might not successfully facilitate learning performance in different learning setting. Although the use of graphics is integrated in designing instruction, many learners are still unable to acquire the intended information through given graphics if they fail to actively incorporate elaboration strategies for learning (Rieber, 1994). It is worthwhile to examine whether the used graphics accurately illustrate and clarify the content material being presented. It is also essential to carefully study how the information can be constructed and perceived by individuals based on their cognitive ability, characteristic, learning experience and knowledge background.

Literature has addressed that individuals benefit from graphics differently due to several factors. For example, task difficulty for specific group of learners (Dwyer & Parkhurst, 1984), levels of IQ among learners (Berry & Dwyer, 1982; Dwyer, 1983), reading ability of learners (Reid & Beveridge, 1986; Samuels, 1970), different graphic complexity (Dwyer & Parkhurst , 1984), and presenting strategies (e.g. animation) used with graphics (Mayer & Anderson, 1992; Rieber, 1989) are considerations for using graphics.

During recent years, there has been a growing interest and development effort for graphical innovations, such as three-D and virtual reality technology. These technical advances make the communication of the information available in a wide variety of approaches. To design effective visual stimuli used in computer assisted instruction, it is necessary to investigate specific cognitive level, characteristic, and match stimuli design with specific kind of learners. For example, should visual displays be simple or more complex, what colors and cues should be used, and in what sequence should these graphics be presented. Questions of this type should then be compared with specific cognitive ability and to a specific learning outcome so that the learners with specific cognitive ability which may have information processing disadvantages might be improved through the use of graphics.

Summary

The above review addresses implications for the use of graphics in computer assisted instruction such as the treatment of graphics in relation to the type of learning tasks given, metacognitive skills, the learning patterns of learners, and the level of students' ability to functionally use the given representation to incorporate into their own construction of knowledge. These issues addressed emphasize the importance of carefully study about how learner learn from graphics prior to design work. Dual coding theory and level of processing theory regarding learning from graphics suggest the differences in learner's processing ability and process patterns can be factors accounting for the effect of using computer graphics. Individual differences are also important considerations in employing graphics for motivation and attention purposes. Whether the computer graphics helps or retards the thinking process of in the learning context depends on whether the learner can use the graphically representing ideas to integrate the main concept of the content and, thus, to form the cognitive connections. With this implication, the use of computer graphics should take into considerations of the relation provided in linking the cognitive components: attending, coding, and processing that function as an anchoring schema in helping learners reconstructing and extracting the learning concepts rather than just an aid for decorating computer screens.

In order to provide reliable support for using computer graphics, considerably more research and development in exploring graphics in different cognitive acquisition are desired. The process of design computer graphics should start with the process of understanding how and why learners learn from graphics and then trying to project the key to mastering the learning tasks from the graphics designed. Although the advance technology has provided graphic designers with various new design opportunities, the central element to successful graphic design lies on the understanding of how learners learn from graphics.

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