DOCUMENT RESUME

ED 373 707 IR 016 717

AUTHOR	ChanLin, Lih-Juan; Reeves, Thomas C.
TITLE	New Directions for Research on Graphics Design for Interactive Learning Environments.
PUB DATE	94
NOTE	15p.; In: Proceedings of Selected Research and Development Presentations at the 1994 National Convention of the Association for Educational Communications and Technology Sponsored by the Research and Theory Division (16th, Nashville, TN, February 16-20, 1994); see IR 016 784.
PUB TYPE	Information Analyses (070) -- Speeches/Conference Papers (150)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	Cognitive Processes; *Computer Graphics; Computer Software Evaluation; *Design; *Educational Environment; Educational Research; Foreign Countries; Interaction; Literature Reviews; Models; Research Methodology; Research Needs; Theories; Theory Practice Relationship
IDENTIFIERS	Interactive Systems; *Learning Environments

ABSTRACT

Research that has been conducted relating to the use of graphics and how various design variables interact with graphics in influencing the process of learning within individuals is explored. Research directions and approaches that may provide enhanced guidelines for integrating graphics into future interactive learning environments are described. The substantial research to date has provided a foundation for further research to guide the design of interactive learning environments. Six recommendations are made to guide such research: (1) a variety of paradigms should be explored, including positivist, interpretivist, qualitative, critical theory, and postmodernist; (2) research should be grounded in broad and comprehensive theory; (3) study subjects should be involved in learning that is meaningful for them; (4) research should use commercially viable products; (5) field-based research is preferable; and (6) research protocols used by software usability testing laboratories may provide guidance. Questions should focus on how learners process graphics. (Contains 62 references.) (SLD)

Title:

New Directions for Research on Graphics Design for Interactive Learning Environments

Authors.
Lih-Juan ChanLin, Ed.D.
Fu-Jen Catholic University
Hsien-Chuang, Taipei

Thomas C. Reeves, Ph.D.
The University of Georgia
Athens, GA 30602

INTRODUCTION

The relationships among graphical, motivational, and learning variables are complex in any instructional method, but especially in interactive learning environments. Whereas media such as textbooks and television basically provide graphics or video images for passive viewing, computer-based media incorporate graphics that engage learners in more dynamic ways (Nishida, 1992; Alesandrini, 1987). The two (and sometimes three) dimensional integration of graphics with text as an integrated whole in interactive learning environments has the potential to motivate students to interact more directly and voluntarily with graphical information. This potential is greater than in printed materials in which graphics often play a more ancillary role.

Some maintain that computer graphics design has entered a new era with the advent of 3-D animated graphics and virtual reality systems (Wooley, 1992). The principles underlying the role of graphics in motivating students and supporting their knowledge and skill acquisition must be incorporated into the design of all types of interactive learning environments, especially if these environments are expected to support higher-order learning such as the construction of mental models (Friedman, 1993). If the hypothesis that graphics play an important role in helping students to acquire knowledge and skills and/or in increasing students' motivation to persevere in computer-based learning, then guidelines for the design of interactive learning environments should include prescriptions for the use of graphics that maximize motivation and learning.

There is a body of literature that addresses design guidelines for integrating graphics into computer-based instructional materials (e.g., Alesandrini, 1985; Alesandrini, 1987; Faiola & DeBloois, 1988; Marcus, 1992; Morrison, Ross, O'Dell, Schultz, & Higginbotham-Wheat, 1989). However, the guidelines are mostly concerned with how the technical aspects of graphics (e.g., color or realism) can be integrated into the design of computer-based instruction. Although the integration of technical innovations (more colors, more pixels, faster access times) provides a wide variety of new opportunities for instructional designers to dazzle their audiences, the justification for using specific graphic representations and treatments should be based upon a "learner-centered" perspective, rather than a "technocentric" one (Rieber, 1989a). In other words, instead of evaluating interactive materials based on how well the capabilities of the hardware and software are utilized, it is much more important to assess the roles graphics play as instructional dimensions that enhance learning and motivation.

Despite the widespread use of graphics in instruction, the psychological literature about "how" people acquire knowledge and make inferences from graphics is sparse. How learners integrate text and graphics and whether their ability to learn from graphics varies with their level of visual literacy, experience, or expertise within a specialized domain are also unresolved questions (Friedman, 1993). There is some evidence that people with different experience in a specific knowledge area employ different strategies in viewing and interacting with graphics (ChanLin, 1993; Horton, 1991). For example, given specific instructional objectives, the use of abstract graphics to present scientific information to more-experienced viewers might be contradicted with less-experienced viewers. Unfortunately, there are few empirically-based guidelines about how best to convey a specific graphic image to learners that have different levels of familiarity with the content of the graphic. Instead, research in graphics in interactive learning environments (and other media for education and training) has focused on the physical variables of graphics, such as pictures vs. drawings or color vs. monochrome or large vs. small displays (cf., Friedman, 1993). What we really want to know is how graphics enhance motivation and support learning across many different individual characteristics, objectives, media, and other instructional dimensions.

The main objective of this paper is to review research that has been conducted related to the use of graphics and how various design variables interact with graphics in influencing the process of learning within individuals. It is also the intent of this paper to describe research directions and approaches that may provide enhanced guidelines for integrating graphics into future interactive learning environments.

PREVIOUS RESEARCH ON GRAPHICS

In the past, graphics research focused extensively on the effects of graphics in various media (e.g., in books versus computer-based instruction) or in various formats (e.g., static versus animated). The primary methodologies employed in these studies involved comparing different types of instruction with different graphical treatments. The findings of this research are not always in favor to the use of graphics or specific graphical formats. For example, a specific graphic format might be found to facilitate memorization among a specific group of learners engaged in a specific recognition task, but fail to achieve the same instructional intent among another group of learners or with a different task (Dwyer, 1987). Although it is dismaying that so many of the graphical design guidelines have been issued in the absence of empirical evidence (Friedman, 1993), this tendency simply reflects the complexity of establishing the effects of graphics in interactive learning environments. The situation is further complicated by the fact that what limited research base exists was established in relatively simple computer-based displays (e.g., forty characters, line drawings, and eight colors on one screen) rather than in the multi-windowed, photo-realistic, full-spectrum computer presentations that are the hallmark of contemporary interactive learning environments.

Following precedents set by traditional graphic researchers, many recent studies have tested hypotheses using interactive systems that were already examined in text and other media. Each of these studies has taken a slightly different perspective on how to improve learning from graphics. For example, some studies focused on comparing the relative learning effectiveness between computer-based instruction (CBI) with graphics and CBI without graphics (e.g., Alesandrini & Rigney, 1981). Other studies were carried out to examine the relative effectiveness of different degrees of realism in computer graphics (e.g., Gage, 1989). Still others compared the use of different graphic cues in guiding students' attention (e.g., Beck, 1987). These studies tried to support the assumptions and beliefs of proponents of CBI about the role of graphics in interactive learning. Example beliefs include: 1) pictures are effective because they are easier to perceive than verbal information; 2) learning is somehow proportional to degree of fidelity in graphics; and 3) pictures provide redundant codes for processing information.

Some of these studies have provided interesting results. For example, several studies have been conducted to compare graphical versus verbal instruction in guiding comprehension of science content within different scientific fields. Rigney and Lutz (1976) compared two versions of chemistry CAI tutorials, an all-verbal presentation and a verbal-plus-graphics presentation. The results showed that learners who studied the verbal-plus-graphics version scored higher on tests of knowledge, comprehension, and application of concepts. More favorable ratings of the learning materials were also obtained from the verbal-plus-graphics group.

To test the effects of graphics in CBI, two experimental studies were conducted by Alesandrini and Rigney (1981) in introductory psychology courses. In the first experiment students were assigned to either all verbal or verbal-graphic conditions; learning results favored the verbal-graphics presentation. The second experiment was conducted to test the effectiveness of a pictorial review task compared to a read-twice control. The results indicated that the pictorial review condition facilitated performance more than re-reading; pictorial review produced more favorable attitudes as well. If these studies were exemplary of most of the extant research, the hypothesis that pictures provide beneficial effects in terms of guiding and reinforcing learning in CAI would be strongly supported.

Unfortunately, the support for using graphics in interactive instructional materials is inconsistent. In a reading comprehension study, Edyburn (1982) found no significant increase in performance for a graphic CAI group compared with a non-graphic CAI group. In learning comma usage, the results of Smith's (1985) study showed that a graphic treatment was not significantly better than a non-graphic treatment. Surber and Leeder (1988) reported that provision of graphic feedback in CAI materials did not enhance either achievement or motivation in spelling. One explanation for the inconsistent results among these studies may be that related variables such as variation in learners' abilities, differences in the nature of the learning tasks, and variance in design quality across different CAI programs have not been sufficiently assessed or controlled in the studies. In short, the relationship between graphics and learning is probably much more complex than the relatively simplistic research designs employed to date can handle.

Whereas some designers of interactive learning environments seem to believe that graphics should be as realistic as possible to enhance motivation and learning, the degree of realism required in graphics may vary for different instructional tasks (Dwyer, 1970). Gage (1989), for example, used three different formats for computer graphics among three treatment groups. The three treatment groups used highly realistic graphics, moderately realistic graphics, and slightly realistic graphics. A control group received text instruction with illustrations. The analysis of posttest scores with the pretest as a covariate showed significant differences between treatments. The results showed that the treatment with the least realistic graphics had the highest achievement. Highly detailed graphics did not contribute to learning in this study.

Interpreting this study requires the researcher to consider cognitive and metacognitive process rather than simple perception variables. Perhaps the main function of graphics in some contexts is to help students learn by differentiating relevant cues. Therefore, excessive realism may actually interfere with the transmission of information because irrelevant cues might also be activated in processing the information from realistic images. From the standpoint of economy and instructional effectiveness, simpler graphics may interfere less and thus be more effective. Dwyer concluded that different graphical formats assist learning and comprehension differently (see reviews by Dwyer, 1970, 1988). According to Dwyer, if the purpose of instruction is to bring the students into close touch with reality, e.g., to encourage an emotional response, a realistic graphical format may be more effective than an abstract one. The appropriateness of realistic details in graphics is related to differences in the learning tasks given to the student, the time allowed for interacting with graphics, and the cognitive capabilities of students to process the information provided in the graphics.

GRAPHICAL, MOTIVATIONAL, AND LEARNING VARIABLES

Although the integration of new design elements (e.g., QuickTime movies) is a popular trend in producing graphics for interactive learning, the theoretical and empirical foundations for their use have not been established by research. It appears that many dimensions of graphics themselves are poorly understood with respect to their instructional effects and implications for design. Which format of graphics to use, when to use it, how to use it, what to use it with, and to whom to apply it are all reasonable questions that suggest the complexity of the relationships among graphics, motivation, and learning.

Some researchers and theorists have attempted to deal with this complexity. For example, Kaufmann (1985) found that the effects of graphics vary with task familiarity and problem-solving mode, with imagery being particularly useful in novel situations. Other studies have examined the effects of different elaboration of visual materials in different levels of practice in computer-based learning materials (e.g., Rieber, 1989b; Rieber, 1990a, b; Rieber, Boyce, & Assad, 1990; Rieber & Hannafin, 1988). Researchers also investigated the affective effects of graphics, such as in meeting emotional needs, as an essential element in supporting motivation and knowledge acquisition (ChanLin, 1993; Eisner, 1985). These studies assume that the relationships among graphics, motivation, and learning should not be studied unless both the characteristics of learners and the learning environment are well integrated into the research.

Task differences may also play an important role in explaining the effects of graphics. Cunningham's (1988) meta-analysis concluded that the most effective subject areas for employing computer graphics in learning materials are: geometry, physics, chemistry, and health education. Cunningham reported that representational graphics were the most widely used graphic level in these subjects, while animated graphics were the most efficiently employed graphic form.

Different tasks and different access conditions for interacting with pictures may also influence the level of understanding learners achieve from graphics. Thomas (1989) studied computer graphics integrated into a problem-solving activity. He found that task differences influenced the level of interaction with graphics. Computer graphics integrated into problem-solving activities improved students' attitudes and achievement in learning functional concepts, but not in learning transformational concepts. In addition, compared with a divergent approach (students allowed to change graphics throughout the activities), the convergent-task approach (select a picture to work with throughout the activities) resulted in higher levels of task-motivation and helped students develop a better understanding of functions.

Computer graphics may also be employed as a learning aid in terms of a memory organizer for formation of concepts. For example, Krahn and Blanchaer (1986) use computer-generated graphics as organizers to help students learn medical concepts. Steinberg, Baskin and Hofer (1986) and Steinberg, Baskin and Matthews (1985) used computer-generated graphics as a memory tool for students to employ in problem-solving tasks. Presenting key information in instruction together with visuals can serve as a memory cue for encoding and retaining the knowledge concepts.

There is also evidence indicating that graphics might have differential effectiveness with different types of learners. In a study of the effects of computer graphics in first year algebra CBI, Payne (1988) investigated the effects of instruction on solving equations graphically to instruction on solving linear equation algebraically. There were no significant differences between experimental subjects (using computer generated graphs prior to traditional instruction) and control subjects (receiving traditional instruction only). However, students with high general reasoning or computational learning scores who had the graphical treatment achieved more on higher level behaviors than their counterparts who experienced the algebraic treatment.

The use of different instructional strategies may also influence the degree to which students can benefit from specific types of graphics. To evaluate various strategies used together with graphics in an algebra word problem-solving program, four experiments were conducted among undergraduate students (Reed, 1985). It was observed that the effective use of graphics requires a "learning by coaching" condition, especially for low achievement students. From Reed's (1985) and Thomas' (1989) studies, it is suggested that the instructional strategies employed for presenting graphics may influence the way information is processed and encoded.

Although using pictures might promote deeper levels of mental processing during encoding, their presence may provide little facilitation of memory tasks in other contexts. Rieber and his colleagues examined the effects of computer animated graphics in physics instruction among different grade levels (Rieber, 1989b; Rieber, 1990a, b; Rieber, Boyce & Assad, 1990; Rieber & Hannafin, 1988). They speculated that animated presentations provide clear and precise external illustrations to help students visualize physical laws which involve changes in speed and the path of travel. However, they found that the optimal use of animated graphics was related to cognitive practice activities employed by learners. In short, learners' metacognitive processes play a much more important role in interpreting and reconstructing their understanding of concepts than graphics per se. More research investigating how learners interact with graphics metacognitively and how graphics should be presented to help the conceptual reconstructing process is essential.

In some quarters visual thinking is considered an important way of learning problem-solving and promoting creativity (O'Connell, 1992). Reed (198[illegible] well as Treadgill-Sowder, Sowder, Moyer, and Moyer (1985) have shown that graphic presentation of mathematical story problems can lead to improved performance. However, creativity and visual thinking are difficult to measure. Although some studies indicate that higher level learning tasks benefit most from the graphics enhanced instruction, the effects of graphical representations used in higher level learning tasks are elusive and immeasurable (Brown, 1992; Levie, 1987). Good reasoning skills depend crucially on the vigorous exercise of imagination (Perkins, 1985). Graphics may provide support for visually processing information to generate multi-dimensional links for imaginative problem solution. In any case, it should be clear that justifying graphics in interactive learning environments goes beyond the measurement of their effects on academic achievement (Levie, 1987).

DIRECTIONS FOR FUTURE RESEARCH

Empirical research in graphics has focused rather extensively on picture-text differences and physical variables (e.g., color vs. black and white) to the exclusion of other relevant factors, such as differences in instructional purposes, differences in graphical presentations, and the interactions among perception, learner characteristics, and knowledge level. The research cited above seems to suggest that the optimal use of graphics is determined by more than visual factors such as color cueing, labeling, realism, and animation. Research based principles are needed that describe the level of practice permitted with graphics, variations among the cognitive tasks required in various subject areas, and how learners actually employ their own strategies to mentally integrate the graphics and the images they generate when processing information.

Of course, research findings about whether graphical information is perceived and remembered better than text or which format of graphics is more efficient than others, are always conditional. The condition is determined by variables specified by the group of learners tested, the types of tasks given, the kinds of strategies instructed, and the graphical treatments in the study. For example, although some studies have found simple line drawings more effective than other formats for promoting learning, considerable variation exists among researchers in defining graphic formats from simple to complex. How realistic must a picture be to be defined as a realistic representation or how simple must a picture be to be defined as a simple representation? More importantly, how can these research findings be applied in commonplace instructional settings? The same concern is observed with respect to the cognitive practice given to the learners. Studies have found that embedded questions promote the use of graphics in learning because they allow deeper levels of cognitive processing. However, how much practice is enough for different types of learners? Other questions persist. How should questions be presented with graphics to achieve a given learning task? What level of processing of graphics is actually employed by learners in a given learning task?

Our review of several years of research in graphics indicates that the effectiveness of visuals is not equally observed among different groups of learners for different kinds of objectives when integrated with different kinds of instructional strategies. The bottom line appears to be that even the research-based principles revealed by researchers in the past are specific to the testing situations in which they were found, with only limited potential of generalizability to different learning situations.

Graphics researchers try to study the complexity of the real world by testing hypotheses devised from a narrow range of literature (Levie, 1987). "An aerial view of the picture research literature would look like a group of small tropical islands with only a few connecting bridges in between." (Levie, 1987, pp. 26). People who conduct picture research usually ally their research to some field, and tend to focus on the literature in their own area, such as perception, picture recognition, picture memory, concept learning, or problem-solving. Much graphics research tries to answer questions from a single perspective. Dealing with the complexity in learning in interactive learning environments is a major challenge.

One of the problems with the existing research base is that it has been conducted according to what Salomon (1991) calls an analytical research approach, usually involving controlled experiments. These experimental studies have focused on assessing the effects of discrete graphical variables (e.g., color versus black and white or photographs versus line drawings) on a limited range of learning outcomes (e.g., memorization).

Salomon (1991) calls for increased systemic research in instructional technology and related fields to investigate the effects of instructional programs and products in realistic settings. Salomon says, "Without observations of the whole system of interrelated events, hypotheses to be tested could easily pertain to the educationally least significant and pertinent aspects" (p. 17). We argue that such has been the case with much of the research on graphics and computer-based learning environments.

Of course, years of experimental studies have yielded some generalizable principles. For obtaining/guiding attention, graphics are more easily perceived and more distinctive than words (Paivio, 1990). Graphics can extend the time readers are willing to spend on learning due to the capability of graphics to arouse certain emotions (Peeck, 1987). Based upon their familiarity, pictures have a "dual reality" for presenting objects themselves and for functioning as surrogates for other abstract concepts (Levie, 1987). Graphics can be direct representations or analogical presentations for relating the unfamiliar to the familiar (Alesandrini, 1985). Graphics can support understanding of the spatial features of an object or facilitate the learning of a sequence of procedures that might require an awkward or lengthy description solely through verbal communications (Hegarty, Carpenter, & Just, 1991). Graphics can allow a deeper processing of information, and thereby they can reinforce the process of encoding (Reid, Brigg & Beveridge, 1983). Dwyer (1970, 1987) concluded that different formats of graphics assist learning and comprehension differently. While these findings are encouraging, they provide an inadequate foundation for guiding design decisions in practical contexts, especially with respect to today's graphical intensive learning environments. We believe that future research should be directed to understanding "how" learners interact with graphics in using interactive learning environments that are pertinent to their personal and academic goals.

THE NEW IMPORTANCE OF GRAPHICS RESEARCH

New technologies abound (e.g., digital movies) and thus many new design elements are being integrated into the production of computer-based instruction. The uses of animation and video capture techniques, such as QuickTime, support learning by allowing students to view the dynamic nature of processes, a factor limited in even the best static graphics. Incorporating various types of animated graphics into interactive learning environments is expected to support motivation and learning.

According to Paivio's dual coding theory (Paivio, 1990), information is easier to retain when coded verbally and visually. Within his definition of dual coding, visual input also refers to the dynamic features of objects and events. Integration of animation features and visual effects can be an effective way of arousing and maintaining the learner's attention during computer-based learning due to the distinctive cues provided in contrast to static forms of information and cueing stimuli (Rieber, 1989a; Hannifin & Peck, 1988).

Recent studies (e.g., Brown, 1992; O'Connell, 1992) have addressed the merits of sophisticated computer graphics in enhancing interaction and exploration. Various graphics treatments, such as three-dimensional modeling, color, and animation, allow viewing from different angles, so much so that students may perceive that they are in virtual environments. Without in-depth assessments using both qualitative and quantitative methods, research might not come up with guidelines for design of these innovative "high tech" learning environments.

Learners perceive graphical information and engage cognitive processes which requires them to select relevant elements from the stimuli to attend. The use of animation, three-D images, and/or digital video can help students extract the central concepts within a context, and at the same time conceptualize what might not be explained clearly in the text. However, issues about how graphics relate to the central context to be presented, how they guide learners to comprehend new concepts, and how they can reinforce the process of learning require more research efforts aimed at providing a better basis for incorporating state-of-the-art graphics into the design of computer-based materials.

In a review of instructional visuals, Dwyer (1988) concludes that visualization provides potential impact on increasing learning interest, guiding thinking, and supporting learning through reinforcement and discrimination of relevant cues. To differentiate the purposes of using graphics in CBI, four instructional functions are used below: gaining attention, relating areas of familiarity, guiding comprehension, and reinforcing what needs to be learned. If our main research goal is to help developers incorporate graphics into interactive learning environments, it may be worthwhile to look at these functions individually in order to help focus research directions.

Research on Obtaining/Guiding Attention Through Graphics Is Needed

Attention-gaining is an important initial event of instruction (Gagnè, Briggs, & Wager, 1992). Graphics usually convey non-verbal interactions through their own symbolic representations. Due to the differences between pictures and words in the sensory and physical features, pictures are more discriminable and more distinctive than words (Kobayashi, 1986; Paivio, 1990). In addition to the distinctive physical features of graphics versus words, graphics are also often used for arousing certain emotional impact or attitudes toward new content. Many pictorial studies (e.g. Levie & Lentz, 1982; Rigney & Lutz, 1976; Swell & Moore, 1980) support the emotional impact graphics have in reading. For example, Peeck (1987) argues that the affective effect of pictures is due to their features in maintaining a high level of concentration on symbolic response patterns. Pictures may often facilitate in extending the time readers are willing to spend on learning (Peeck, 1987). The emotional effects of images have been addressed in some studies, but little research has been done in this area with interactive learning environments.

Much research has been conducted to examine the factors that influence the processes by which pictures are noticed and attended (e.g., Beck, 1984; Butler & McKelvie, 1985; Jennings & Dwyer, 1985). Physical characteristics, such as color, position, contrast, motion, and the size of visuals to affect different communication levels are emphasized in these studies (Goldsmith, 1987). More research needs to be done to understand the reciprocal relations between graphics and perceptions of various learners in order to provide instructional designers with design guidelines for helping students to see what needs to be seen. Further, field-based research is required to study these variables within actual instructional contexts (in addition to laboratories) to determine how learners attend to information through the use of graphics.

Research on Relating Areas of Familiarity Through Graphics Is Needed

Graphic representations can convey information rapidly and can be recalled rapidly due to their "dual reality," i.e., they represent objects themselves, and they function as surrogates for other concrete objects or even abstract concept (Levie, 1987). When a picture is used, it is perceived and interpreted by viewers based on their own understanding and experience in constructing a meaningful representation. Pictures may be direct portrayals or analogical representations used to relate what learners already know to the understanding of new concepts. Although some fundamental skills for visual recognition are innate, decoding pictorial information is related with picture-viewing experience, culture-bound conventions, and knowledge experience (Levie, 1987).

Since we use images to communicate, we need to know how to choose the most valuable images to express ideas (Nanny, 1990). In interactive learning environments, one of the mainstays of graphical user interfaces is to use the appropriate graphical representation to present a resource, an option or an action (Cates, 1993). Using appropriate pictures for different audiences at the right time is challenging. More research needs to be done to observe how people from different fields, different levels of expertise in certain areas, or different age groups perceive, interpret, and interact with the graphics in a learning environment.

Research on Guiding Comprehension Through Graphics Is Needed

Using graphics for guiding comprehension is widely used among scientific and technical information. For examples, Rieber and his colleagues used animated graphics in presenting an introduction to Newton's Law of Motion (Rieber, 1989b; Rieber, 1990a, b; Rieber, Boyce, & Assad, 1990; Rieber & Hannafin, 1988). During recent years, there has been a growing interest and development effort for graphical innovations. These technical advances make the communication of the information available in a wide variety of approaches. The visual properties of graphics help learners understand spatial features of an object or a sequence of procedures that might require an awkward or lengthy description solely through verbal communication (Hegarty, Carpenter, & Just, 1991). However, it is also easy "to be superficial to dazzle someone with beautiful graphics" when using technology (Dam, 1992). Research on how graphics can be presented to make the abstract and complex concepts concrete and simplified is needed.

In addition to conveying information that is spatially related, the use of graphics also provides various types of assistance in organizing concepts and principles into elaborate networks (e.g., mental models). Mental models are used to integrate information into a holistic perspective or useful strategy. The use of graphics as an organizer has been shown to be an effective thinking tool and widely applied in various subjects for both inductive and deductive thinking (e.g., Clarke, 1991; Tajika, Taniguchi, Yamamoto, & Mayer, 1988; Krahn & Blanchaer, 1986). Graphics used for this purpose provide learners ways to visualize and control their thinking about content in the subject areas. However, studies designed to observe and contrast the visualization processes used by experts and novices as they construct mental models are needed (Friedman, 1993, Jih & Reeves, 1992).

Most research is conducted to compare and analyze the outcomes among specific graphical treatments and other types of treatments. Little research has been done to build understanding of the strategies students actually employ to construct understanding from graphics. More research needs to be done through documenting the processes employed by students to learn new knowledge, skills, and attitudes through the use of graphics.

Research on Reinforcing Learning Through Graphics Is Needed

Pictorial stimuli are used to help readers emphasize concepts to be learned (Beck, 1987). Pictures are often used in facilitating the encoding process (Levie & Lentz, 1982; Reid, Brigg & Beveridge, 1983). It is considered that when presented together with text, more cues are provided to allow deeper processing of the intended information. The provision of graphics also permits learners to interact with the materials with different dimensions, which encourages the information to be processed in a more elaborated way. Used as an encoding cue, graphic representations provide interpretation to given verbal information so that the information can be communicated more explicitly and accurately (Morris & Hampton, 1983; Alesandrini & Rigney, 1981). With denotation of concrete representations to textual materials, the information is more easily retained in memory because both verbal and image systems are activated in storing the information. Under the assumptions of dual coding (Paivio, 1990), when information is presented verbally and visually, it can be retained longer in memory because both memory systems are used.

To reinforce learning, students need to deeply process the information through the use of their own cognitive strategies to relate both verbal and visual information from the instruction. Research should focus on how information should be presented and what other instructional strategies should be included to promote the use of students' own metacognition for deeper processing.

NEW DIRECTIONS FOR GRAPHICS RESEARCH

Six recommendations are made to guide graphics research in interactive learning environments:

1. A variety of research paradigms should be explored in conducting graphics research (e.g., a. positivist, quantitative, b. interpretivist, qualitative, and c. critical theory, postmodernist). Studies employing multiple methods should be considered.

2. Researchers should attempt to ground their research in broad, comprehensive theories of human perception, memory, and learning. Further, research that does not reflect a deep appreciation of the theory and research on graphics that has built up over the past fifty years will likely rediscover what is already known or lead to irrelevant conclusions.

3. Subjects in graphics studies should be involved in learning that is personally meaningful and has real consequences for them.

4. Graphics research should employ commercially viable interactive products or products that are under development as opposed to the "nonsense" materials used in some earlier studies. The continued use of irrelevant or content-free materials is highly unlikely to provide us with useful principles for design of interactive learning environments.

5. Although laboratory studies can be useful, field-based research should be preferred to increase the generalizability of research findings.

6. Regardless of whether research is conducted in labs or the field (e.g., schools, training centers, businesses), the research protocols used by software usability testing laboratories may provide excellent guidance for the conduct of these studies (Nielsen, 1993). (The Learning and Performance Support Laboratory at The University of Georgia is establishing two facilities, one fixed and one mobile, to employ usability testing strategies in research on graphics, navigation, and mental models in interactive learning environments and performance support systems.)

SUMMARY

Substantial research on graphics using a wide variety of media has provided a foundation for further research that may provide an enhanced basis for guiding the design of interactive learning environments. However, we maintain that future research demands new directions in terms of both the questions asked and the methods used by graphics researchers. Questions should be focused on understanding "how" learners process graphics. Methods should be expanded to include a wider spectrum of research paradigms. All graphics research should be guided by in- depth understanding of theory and research related to perception, memory, learning, and other cognitive processes.

REFERENCES

Alesandrini, K. L. (1987). Computer graphics in learning and instruction. In H. A. Houghton & D. M. Willows (Eds.), *The Psychology of Illustration: Vol. 2. Instructional issues* (pp. 159-188). New York: Spring-Verlag.

Alesandrini, K. L. (1985). A look at computer graphics. *The Computing Teacher, 12*(5), 23-25.

Alesandrini, K. L. & Rigney, J. W. (1981). Pictorial presentation and review strategies in science learning. *Journal of Research in Science Teaching, 18*(5), 465-474.

Beck, C. R. (1984). Visual cueing strategies: Pictorial, textual, and combinational effects. *Educational Communication and Technology Journal, 32*, 207-216.

Beck, C. R. (1987). Pictorial cueing strategies for encoding and retrieving information. *International Journal of Instructional Media, 14*(4), 332-343.

Brown, J. (1992). The multi-faceted blackboard: Computer graphics in higher education. In S. Cunningham & R. J. Hubbold (Eds.), *Interactive learning through visualization* (pp. 103-109). New York: Springer-Verlag.

Butler, L. & McKelvie, S. L. (1985). Processing of form: Further evidence for the necessary of attention. *Perceptual and Motor Skills, 61*, 215-221.

Cates, W. M. (1993, April). *Making the most of imagery: Theoretical issues in selecting metaphorical images*. Paper presented at the Annual Meeting of the American Educational Research Association, Atlanta, GA.

ChanLin, L. (1993). *Motivational strategies in computer graphics design: An assessment through a case study among veterinary students*. Unpublished doctoral dissertation, The University of Georgia, Athens, GA.

Clarke, J. H. (1991). Graphic organizers: Frames for teaching patterns of thinking. In A. L. Costa (Ed.), *Developing minds: A resource book for teaching thinking: Vol. 2.* (pp. 224-231). Alexandria, VA: Association for Supervision and Curriculum Development.

Cunningham, A. J. (1988). The contribution of computer generated instructional graphics on measured achievement gains: A meta-analysis. *Dissertation Abstracts International*. 50/02A. (ERIC Document Reproduction Service No.: AAC8910290).

Dam, A. (1992). Electronic books and interactive illustrations. In S. Cunningham & R. J. Hubbold (Eds.), *Interactive learning through visualization*, 9-24. New York: Springer-Verlag.

Dwyer, F. M. (1988). Examining the symbiotic relationship between verbal and visual literacy in terms of facilitating student achievement. *Reading Psychology, 9*(4), 365-380.

Dwyer, F. M. (1987). Visual literacy's first dimension: Cognitive information acquisition. In F. M. Dwyer (Ed.), *Enhancing visualized instruction: Recommendations for practitioners.* State College, PA: Learning Service.

Dwyer, F. M. (1970). Exploratory studies in the effectiveness of visual illustrations. *Audio Visual Communication Review, 18*, 109-122.

Edyburn, D. L. (1982). *The effects of two levels of microcomputer graphics on reading comprehension.* Normal, IL: Illinois State University. (ERIC Document Reproduction Service No. ED 218 593).

Eisner, E. (1985). Aesthetic modes of knowing. In E. Eisner (Ed.), *Learning and teaching the ways of knowing. Eighty-four yearbook of the National Society for the Study of Education* (pp. 23-26). Chicago: University of Chicago Press.

Faiola, T. & DeBloois, M. L. (1988). Designing a visual factors-based screen display interface: the new role of the graphic technologist. *Educational Technology, 28* (8), 12-21.

Friedman, A. (1993). Designing graphics to support mental models. In J. M. Spector, M. C. Polson, & D. J. Muraida (Eds.), *Automating instructional design* (pp. 249-288). Englewood Cliffs, NJ: Educational Technology.

Gage, P. L. (1989). *The effectiveness of three studying treatments with visual aids of varying realism in teaching a topic in the physics of wave motion*. Dissertation Abstracts International. 50/07A. (Publication No. AAC8912865).
Gagnè, R. M., Briggs, L. J., & Wager, W. W. (1992). *Principles of instructional design* (4th ed.). Fort Worth, TX: Harcourt Brace Jovanovich College.
Goldsmith, E. (1987). The analysis of illustration in theory and practice. In H. A. Houghton & D. M. Willows (Eds.), *The Psychology of Illustration: Vol. 2. Instructional Issues* (pp. 53-82). New York: Springer-Verlag.
Hannifin, M. & Peck, K. (1988). *The design, development, and evaluation of instructional software*. New York: Macmillan.
Hegarty, M., Carpenter, P. A., & Just, M. A. (1991). Diagrams in the comprehension of scientific texts. In R. Barr, M. L. Kamil, P. Mosenthal, & P. D. Pearson (Eds.), *Handbook of reading research, Vol. 2* (pp. 641-668). New York: Longman.
Horton, W. (1991). *Illustrating computer documentation*. New York: John Wiley & Son, Inc.
Jennings, T. & Dwyer, F. (1985). The instructional effect of differential cueing strategies in facilitating student achievement of different education objectives. *International Journal of Instructional Media, 12*, 8-20.
Jih, H. J. & Reeves, T. C. (1992). Mental models: A research focus for interactive learning systems. *Educational Technology Research and Development, 40*(3), 39-53.
Kaufmann, G. (1985). A theory of symbolic representation in problem solving. *Journal of Mental Imagery, 9*, 51-70.
Kobayashi, S. (1986). Theoretical issues concerning superiority of pictures over words and sentences in memory. *Perceptual and Motor Skills, 63*, 783-792.
Krahn, C. G. & Blanchaer, M. C. (1986). Using an advance organizer to improve knowledge application by medical students in computer-based clinical simulations. *Journal of Computer-Based Instruction, 13* (3), 71-74.
Levie, H. & Lentz, R. (1982). Effects of illustration: A review of research. *Educational Communications and Technology Journal, 30*, 195-232.
Levie, W. H. (1987). Research on pictures: A guide to the literature. In D. M. Willows & H. A. Houghton (Eds.), *The psychology of illustration: Vol. 1. Basic research* (pp. 1-50). New York: Springer-Verlag.
Marcus, A. (1992). *Graphic design for electronic documents and user interfaces*. New York: ACM Press.
Morris, P. E. & Hampton, P. J. (1983). *Imagery and consciousness*. New York: Academic Press.
Morrison, G. R., Ross, S. M., O'Dell, J. K., Schultz, C. W., & Higginbotham-Wheat, N. (1989). Implications for the design of computer-based instruction screens. *Computers in Human Behavior, 5*, 167-173.
Nanny, M. (1990). Interactive images for education. In S. Ambron & K. Hooper (Eds.), *Learning with interactive multimedia: Developing and using multimedia tools in education* (pp. 86-98). Redmond, WA: Microsoft.
Nielsen, J. (1993). *Usability engineering*. Boston: Academic Press.
Nishida, S. (1992). Hyper-simulator based learning environment to enhance human understanding. In S. Cunningham & R. J. Hubbold (Eds.), *Interactive learning through visualization* (pp. 103-109). New York: Springer-Verlag.
O'Connell, K. (1992). Visual ways of knowing, thinking and interacting. In S. Cunningham & R. J. Hubbold (Eds.), *Interactive learning through visualization* (pp. 79-90). New York: Springer-Verlag.
Payne, V. B. (1988). Instructional effects of computer graphics in first year algebra. *Dissertation Abstracts International*, 49/11A. (Publication No. AAC8901383).
Paivio, A. (1990). *Mental representation: A dual coding approach*. New York: Oxford.

Peeck, J. (1987). The role of illustrations in processing and remembering illustrated text. In H. A. Houghton & D. M. Willows (Eds.), *The psychology of illustration: Vol. 2. Instructional issues* (pp. 115-151). New York: Spring-Verlag.
Perkins, D. (1985). Reasoning as imagination. *Interchange, 16*, 14-26.
Reed, S. (1985). Effect of computer graphics on improving estimates to algebra word problems. *Journal of Educational Psychology, 77*(3), 285-298.
Reid, D. J., Brigg, N., & Beveridge, M. (1983). The effect of picture upon the readability of a school science topic. *British Journal of Educational Psychology, 53*, 327-335.
Rieber, L. P. & Hannafin, M. J. (1988). Effects of textual and animated orienting activities and practice on learning from computer-based instruction. *Computers in School, 5*(1/2), 77-89.
Rieber, L. P. (1989a). A review of animation research in computer-based instruction. *Proceedings of the 1989 annual convention of the Association for Educational Communications and Technology, 11*, 369-390.
Rieber, L. P (1989b). The effects of computer animated elaboration strategies and practice on factual and application learning in an elementary science lesson. *Journal of Educational Computing Research, 5*(4), 431-444.
Rieber, L. P., Boyce, M. J., & Assad, C. (1990). The effects of computer animation on adult learning and retrieval tasks. *Journal of Computer-Based Instruction, 17*(2), 46-52.
Rieber, L. P. (1990a). Using computer animated graphics in science instruction with children. *Journal of Educational Psychology, 82*(1), 135-140.
Rieber, L. P. (1990b). The effects of computer animation on adult learning and retrieval tasks. *Journal of Computer-Based Instruction, 17*(2), 46-52.
Rigney, J. W. & Lutz, K. A. (1976). Effect of graphic analogies of concepts in chemistry on learning and attitude. *Journal of Education Psychology, 68*, 305-311.
Salomon, G. (1991). Transcending the qualitative - quantitative debate: The analytic and systemic approaches to educational research. *Educational Researcher, 20*(6), 10-18.
Smith, C. L. (1985). Analysis of student performance in punctuation using graphics versus nongraphic microcomputer instruction. *Delta Pi Epsilon Journal, 27*(2), 105-116.
Steinberg, E. R., Baskin, A. B., & Hofer, E. (1986). Organizational/memory tools: A technique for improving problem solving skills. *Journal of Educational Computing Research, 2*(2), 169-187.
Steinberg, E. R., Baskin, A. B., & Matthews, T. D. (1985). Computer-presented organizational/memory aids as instruction for solving pico-fomi problems. *Journal of Computer-Based Instruction, 12*(2), 44-49.
Surber, J. R. & Leeder, J. A. (1988). The effect of graphic feedback on student motivation. *Journal of Computer Based Instruction, 15*(1), 14-17.
Swell , E. H., Jr., & Moore, R. L. (1980). Cartoon embellishments in informative presentations. *Educational Communication and Technology Journal, 28*, 39-46.
Tajika, H., Taniguchi, A., Yamamoto, K., & Mayer, R. E. (1988). Effects of pictorial advance organizers on passage retention. *Contemporary Educational Psychology, 13*, 133-139.
Thomas, E. J. (1989). A study of the effects of a computer graphics problem-solving activity on student achievement, attitude, and task motivation. *Dissertation Abstracts International*, 51/01A. (Publication No. AAC9015712).
Treadgill-Sowder, J., Sowder, L., Moyer, J. C., & Moyer, M. B. (1985). Cognitive variables and performance on mathematical story problems. *Journal of Experimental Education, 54*, 56-62.
Wooley, B. (1992). *Virtual worlds: A journey into hype and hyperreality*. Cambridge, MA: Blackwell.