Effective Use of Computer Graphics in CAI: A Review of the Literature

Gina Siliauskas

Abstract: Computer graphics technology offering great potential for designing new types of instructional interactions is fast becoming available to the CAI designer. This paper first describes various new graphic display capabilities, then reviews relevant literature that could assist in determining how they could effectively be used in CAI applications. The ability to animate both graphics and text and the ability to directly manipulate graphic elements on screen displays represent revolutionary features. Little research, however, is currently available which could help provide guidelines for the development of instructional applications-for computer graphics.

It has been said that CAI's greatest potential lies in its capability to individualize instruction using interactive techniques (Moore, Nawrocki, & Simutis, 1979). With increased computing power, systems for manipulating data, including programs, text, graphics, video, voice, sound and touch, are rapidly improving, providing us with powerful new tools for interaction. As these systems become increasingly accessible to the CAI designer, there will be a growing need for clarification with regard to instructional applications.

Restrictions in hardware have limited the use of images in CAI programs, and to date more emphasis has been placed on the presentation of text in an interactive mode than on the use of graphics. As a result, CAI programs have been largely dominated by word-oriented dialogues. Current significant advances in computer graphics technology, however, are now resulting in an increasing shift in emphasis from textual to graphic presentations (Bork, 1981; O'Shea & Self, 1983). Our task here will be to examine the emerging capabilities of computer graphics as they apply to CAI and to review relevant research that may assist us in determining their effective use.

WHAT DO WE MEAN BY COMPUTER GRAPHICS?

Images of objects can now be created, stored, and/or manipulated by the computer - this is the *essence* of computer graphics (Lewell, 1985). Marcus (1977) provides us with a

Gina Siliauskas is Manager of Training, Retail Banking, with the Royal Bank of Canada, Montreal, Quebec. She is currently a doctoral student in Educational Technology at Concordia University and her research interests include graphic-based interaction in CAI and authoring techniques for interactive systems. The author gratefully acknowledges the contribution of three anonymous reviewers and the Editor, Robert M. Bernard, to the preparation of this manuscript.

general but useful definition of computer graphics: "any kind of imagery mediated or generated by computer control and most appropriately, but not exclusively, displayed on cathode ray tube screens" (p. 6). Graphics capabilities in computer systems range from the printing of simple characters to sophisticated picture drawing and image manipulation commands. Computer graphic displays have been used to fulfill a variety of functions such as in the automation of manufacturing processes and the production of engineering drawings, architectural plans, and commercial art layouts.

Examples of computer graphic output include: low resolution paper output; high quality black/white or color pictures of real or imaginary objects for slides, films, or video; and images produced on video displays and characterized by user intervention (Foley & Van Dam, 1982). From a CAI design standpoint our focus is the output generated on a video display screen. Great differences can exist with regard to the type of screen image produced, its quality, and the extent to which it can be dynamically controlled by the viewer. This last factor of viewer control can be used as the criterion for categorizing computer graphic applications as either passive or interactive, a distinction we shall see as having significant implications for CAI design.

Current developments in microprocessor technology are resulting in the design of computer systems with a vast range of graphics capabilities. Special graphics processor chips now under development will make text-based computing systems obsolete (Lu, 1986). In addition to enabling us to create more sophisticated images on the screen, including animated programs, graphics-based systems will allow easier integration with text. New microcomputer systems with such revolutionary video capabilities will become the vehicle for the most common instructional applications of computer graphics.

CATEGORIES OF COMPUTER SCREEN DISPLAYS

It is helpful for our purposes to present a scheme for categorizing computer screen displays to use as a descriptive framework for discussing computer graphics applications in CAI. The widely accepted distinction between text and graphics in relation to print can also be applied to static text and static graphics in screen displays. In addition, the ability we now have to animate content to make it dynamic allows us to further distinguish between screen displays.

Text Displays: Static

Jonassen (1982, p. ix) describes text as "written discourse (aggregates of words) in printed form" that can either be displayed on paper or a CRT. Insofar as text presentation techniques on a screen have a visual element, variables such as screen resolution, size, color, and style of characters play a critical role in communicating messages (Heines, 1984; Merrill, 1982). The alphanumeric symbols that comprise text are usually presented in a linear fashion, and have been typically displayed in a static mode in most CAI applications, with the exception of certain limited dynamic features such as scrolling (moving windows of information) and flashing, as if displayed on a printed page.

Graphic Displays: Static

In reviewing the literature on graphic displays, Moore and Nawrocki (1978) suggest "pictorial," "schematic," and "symbolic" as the terms best representative of the categories used to differentiate among them. As we shall see, these classifications can be generalized to computer screen displays as well.

A pictorial display refers to a "representation of objects or events, to include their relationships, but with the representation having some degree of fidelity to the physical characteristics of these objects or events" (Moore & Nawrocki, 1978, p. 33). Examples would include photographs, drawings and other realistic renderings of real-life objects.

The category of schematic displays describes "two-dimensional line drawings showing spatial or temporal relationships" (Moore & Nawrocki, 1978, p. 33), such as blueprints, circuit diagrams, and maps.

Symbolic displays function as "character sets in which each character has a predesignated, but nonlinguistic, referent to a specified object or concept" (Moore & Nawrocki, 1978, p. 33). The use of symbols is part of the field of iconic communication, which focuses on communicating meaning through visual forms. The word "iconic" implies the use of basic visual imagery dependent on "the ability of people to perceive natural form, shape and motion" (Huggins & Entwisle, 1974). This is in contrast to the use of alphanumeric representations which require linear, linguistic interpretations. The elements of iconic messages can be organized non-linearly in multidimensional space allowing numerous interrelations.

This classification of graphic displays is an arbitrary one, and a closer examination of the literature reveals certain definitional problems. Twyman (1979), for example, finds it difficult to distinguish between pictorial and schematic categorizations. Merrill and Bunderson (1979), on the other hand, find the Moore and Nawrocki classification scheme to be restrictive, and suggest adding a fourth category to the three outlined above (i.e., figural displays to represent the illustration of relationships between abstract ideas). Although other categorization schemes for graphic displays exist based on other criteria, we find this one provides us with a useful starting point for discussing screen displays.

Pictorial, schematic, and symbolic graphic displays can now be electronically represented on a CRT screen. Perhaps even more importantly, however, computer graphics technology now allows us to generate entirely new forms of displays. For example, systems are now able to scan various types of information into the computer. Two-dimensional information such as maps or three-dimensional information in the form of descriptions of solid objects can be drawn into the computer to produce graphic displays, vastly extending our capabilities to graphically represent information. In view of such capabilities, Greenberg (1982), has expanded the definition of computer graphics to include "the communication of graphic (non-alphanumeric) data *to or from* the machine " (p. 7).

Foley and Van Dam (1982) refer to computer graphics technology as "the most important mechanized means of producing and reproducing pictures since the invention of photography and television; it also has the added advantage that with the computer we can make pictures of abstract, synthetic objects" (p. 5). In addition to enabling us to portray real objects and to represent abstractions, the new technology allows us to superimpose abstract and realistic representations, creating yet another new form of graphic display (Brooks, 1977).

Text Displays: Dynamic

With the advancing revolution in computer/video display technology, we will be able to manipulate text in a more creative and dynamic way. The movement of text on the screen promises to become a powerful tool. Heines (1984) offers the following as examples of this potential of text: "...it can be displayed at various speeds, using pauses to add emphasis to key words. In addition, words and short phrases can often be effectively animated across the screen to denote a flow of information and/or materials" (p. 110).

Graphic Displays: Dynamic

All of the graphic displays described previously as being static now have the potential to be dynamic. The ability to add movement to static images represents a powerful tool for communication and information purposes. In addition, the fact that computer/video systems are now capable of creating, storing, retrieving, and manipulating new forms of dynamic images in real time (at a rate which reflects the perceived outside world) or, if desired, at a rate not consistent with real time (slower or faster), has significant implications for CAI applications. A general description of various new forms of dynamic displays follows.

Dynamic models. Dynamic models have properties built into the model description which enable them to change their characteristics within the limits determined by the designer (Glassner, 1984). The use of dynamic graphics is important in the animation of models. For example, a static model of our solar system can only be moved about on the screen, or presented in different perspectives or scales. Changing this model into a dynamic representation, however, permits the movement of planets within the solar system. This ability to move or change the shape of internal elements is what distinguishes static from dynamic models.

Techniques for what are termed "update dynamics" (Foley & Van Dam, 1982) refer to changes in the physical properties of the objects being viewed (e.g., shape, color, and size). There are a large number of modes to encode information with respect to time variation in shape and color of objects. Computer graphics systems allow us to define pictures that involve a variety of transformations, including two-dimensional into three-dimensional and perspective transformations. For example, engineers use computer graphics in structural analysis to build finite-element models to determine the distribution of stress in physical structures (Lewell, 1985). Computer graphics enable us to represent dynamically varying images which portray phenomena, either real or abstract, which vary with time and position. Dynamic sequences can, therefore, be used to convey different types of metamorphosis.

Simulations. The capability of computer graphics systems to rapidly display and efficiently move visual elements in a three-dimensional field is of particular significance for simulation and testing purposes. Lewell (1985) suggests that: "Whenever an image can replace a real object, for the purposes of interaction, a graphic simulation could conceivably be devised" (p. 22). In visual flight simulation, for example, a projected display is used to portray a geographical area, with topological and geometric structure of objects and surfaces being dynamically represented (Schachter, 1983).

Dynamic icons. The use of dynamic computer graphics allows us to generate movement in iconic communication as well. In a study on iconic communication, Huggins and Entwisle (1974) proposed that "the moving iconic symbol" is a new medium with special strengths having great applicability to instruction and requiring much additional research. They note that iconic representations characterized by motion and spatial perspective should be especially created to suit the electronic medium.

Dynamic diagrams. Most diagrams have been developed for use on the printed page, and therefore are static and closely related to the accompanying text. Marcus (1977) maintains that an increasingly important use of diagrams will be to organize vast amounts of information into a practical and readable format. He extends the meaning of the word "diagram" to encompass an array of symbols that utilizes not only two-dimensional but three-dimensional space as well. The array of symbols includes alphanumerics, points, lines, and planes, which may be characterized by texture and color.

In defining the parameters which would accommodate a more dynamic and visual approach to structuring diagrams, Marcus (1977) includes the following: "movement of symbols across and into the visual field, layering of information in actual or implied depth

/literal or phenomenal transparency or translucency, color, multiple entry and exit, and figure-field relationships" (p. 6).

By facilitating the use of these visual elements in the design of diagrams, dynamic computer graphics will provide us with the means of extending our capability to convey vast bodies of information.

PASSIVE VERSUS INTERACTIVE APPLICATIONS

In examining the implications of emerging computer graphics capabilities on CAI design, we need to make a critical distinction. Computer graphics applications can be categorized as either passive or interactive, depending on the involvement of the end-user of the application. Passive applications are those in which the viewer does not interact with the display, while interactive applications require an active involvement with the screen image. Sutherland (1970) provides examples of two types of interactive applications which may have instructional consequences. One application involves solving pictorial problems (e.g., topographical mapping and design), the other involves obtaining additional understanding of complex natural phenomena through the use of simulations.

Computer graphic applications which allow the viewer to dynamically control the image on a display surface with regard to content, format, size, and color are referred to as interactive. Control can be exerted by means of various interaction devices such as keyboard, lever, or joystick, each of which signals the user's intention to the computer. Interactive applications allow the system to respond to user input and therefore require two-way communication.

Interactivity thus implies a dialogue between the user and the computer. The computer responds to the signals from the input device by modifying the display. The user perceives this change in display as the response to his or her commands. Martin (1973) differentiates between four types of dialogue:

(1) Dialogue in which precomposed images can be selected by the user, but not otherwise modified in any way;
(2) Dialogue in which images can be modified, but only by alphanumeric means;
(3) Dialogue in which the user can draw or manipulate pictures of objects. The input devices used and the speed of the computer in changing the image give the user the impression of drawing directly on the screen.
(4) Dialogue in which the user is able to create and manipulate symbolic graphic images.

Interaction is achieved through a technology which allows the viewer to adjust certain aspects of the dynamic screen display - speed, for example, the amount of detail shown, or the portion of the image displayed. Techniques for motion dynamics allow the user to employ two perspectives: 1) one in which he is stationary, and 2) one in which he is mobile. In the first case, objects in the display can be moved with respect to the viewer. In the second case, the viewer is able to move around the stationary objects displayed on the screen. The latter technique is best exemplified in its flight simulation application, where the viewer moves in and around various elements of the defined environment.

Techniques for motion dynamics which allow the viewer to be mobile can also be used within the context of a non-realistic screen environment. Viewers can move in and around molecules, two-, three-, or four dimensional mathematical functions or scatter diagrams of data points in two- or three- dimensional space (Foley and Van Dam, 1982). Marcus (1977) describes such a simulated space, "Cybernetic Landscape 1," in which the viewer is able to explore a language space composed of abstract visual forms and conventional textual elements. "No longer bound to the incised, written, or printed sheet," the reader "travels through the text as context" (p. 10).

Sutherland (1965) who regards the display screen on an interactive graphics system as "a window onto a virtual conceptual 3-D universe," elaborates on this application of computer graphics technology: "I think of a computer display as a window on Alice's Wonderland in which a programmer can depict either objects that obey well-known natural laws or purely imaginary objects that follow laws to be written into the program." (1970, p. 57).

Foley and Van Dam (1982) summarize the implications of the capabilities of this new technology:

> Interactive computer graphics allows us to achieve much higher bandwidth man-machine communication using a judicious combination of text with static and dynamic pictures than is possible with text alone. This higher bandwidth makes a significant difference in our ability to understand data, perceive trends, and visualize real or imaginary objects (p. 6).

Opportunities for instructional applications abound as we are now free to experience in a new dynamic medium concepts that have been traditionally confined to textual expression (e.g., mathematical formulas and linear print) (Adams & Fuchs, 1985).

Direct Manipulation

A key feature of interactive graphics displays is the ability to represent objects and to provide a means for manipulating them. Schneiderman (1984) reports that interactive systems exhibiting the following features seem to receive the most enthusiastic user support: visibility of the object of interest; rapid, reversible, incremental actions; and replacement of complex command language by direct manipulation of the object of interest. The best known example of direct manipulation is the video game. The commands are physical actions, including joystick motions, button presses, and knob rotations. The results of actions are obvious and easily reversed.

Schneiderman refers to such interactive systems as "direct manipulation" systems. Users are said to report positive feelings in terms of: mastery of the system, competence in task performance, ease in learning the system, and confidence in their capacity to retain mastery over time.

Spatial data management systems provide another example of direct manipulation systems. Spatial data management is a technique for accessing data through their graphical representations, or "icons," which are arranged in two-dimensional information spaces known as "Ispaces". These systems are comprised of a color, raster-scan display, a touch-sensitive screen, and a joystick. The user is able to travel within an Ispace and zoom in on specific icons for additional detail (Friedell, Barnett, & Kramlich, 1982). Schneiderman (1983) proposes that the success of such systems is dependent on the designer's skill in choosing icons and developing layouts that are natural and easily understood.

RELEVANT RESEARCH

Instructional Graphics

Graphics in general have been assumed to contribute to the effectiveness of communication, including communication for instructional purposes (e.g., Bork, 1981). In a comprehensive review of the literature on the effects of instructional graphics, Moore and Nawrocki (1978) identified six different "theoretic predispositions" (p. 4) underlying the basic assumption that graphics serve to increase the effectiveness of instruction. Graphics are thought to be: 1) perceived more efficiently than other forms of verbal or auditory displays, 2) realistic, 3) preferred by learners, 4) capable of relieving overloaded perceptual channels by adding sensory input; 5) important because perceptual research has shown individual differences in visual ability to be a significant variable, and 6) only part of a whole instructional system. Moore and Nawrocki (1978) found, however, that the assumption that graphics increased instructional effectiveness to be unsubstantiated by empirical research findings, although some studies were found showing positive effects.

Although each medium has its own unique characteristics, the presentation of static images on computer displays can be compared to some extent to the presentation of pictures in a text. Static graphic displays are most often visual representations displayed in support of a textual component. In this context it is useful to refer to the research relating to the instructional effectiveness of text illustrations.

In discussing how the use of pictures can improve the effectiveness of instructional textbooks, Brody (1982) notes the various functions a picture can serve: to reinforce the information presented verbally, to provide additional information, to help ensure retention of information, and to serve as an organizer. Despite the considerable amount of research conducted involving the use of pictures, an understanding of which pictorial elements affect learning from instructional texts is still lacking (Brody, 1982).

Levie and Lentz (1982) note seven different functions of text illustrations categorized as attentional, affective, cognitive, or compensatory. Although they conclude that illustrations can facilitate learning from text, the researchers observe that how they do so is not clear. In terms of the implications for future research, Levie and Lentz (1982) focus on the need to categorize the functions pictures can perform and the need to prescribe how to design for these functions. Wisely and Streeter (1985) in fact present a scheme outlining seventeen functions of static visuals in relation to supporting text. The proposed scheme, however, is based only on intuition and a literature review, and thus requires validation.

Insofar as computer graphics technology extends our ability to represent graphic information, as described earlier, the CAI designer must be prepared to call upon this resource in making design decisions. Until definitive research in this area is available, continuing research should help us identify the conditions in which graphics are a significant adjunct to the instructional process.

Computer Graphics Applications in CAI

Specific research addressing the effectiveness of computer graphics in CAI applications is scarce. A study conducted in 1979 by Moore, Nawrocki and Simutis compared the effectiveness of three types of graphics displays in a CAI lesson, namely low level graphics (schematic representations and boxed alphanumerics), medium level (line drawings), and high level (animation plus line drawings). The type of graphics display was found to have no significant effect on test scores. The researchers, however, noted that the experimental design of the study may have resulted in a masking of any potential effects of graphics during learning. They recommend as a better approach an exploration of the role of graphics in learning in terms of "When, where, how, and with whom are graphics to be used? (p. 13).

By contrast, Rigney and Lutz (1976) had found that animated graphics inserted into one version of a CAI science unit produced higher posttest scores and more positive attitude.s toward the instruction than a non-illustrated control condition. Bernard and Pineault (1984) found a similar overall effect in favor of static illustrations designed to support a computer-based instructional unit on visual anatomy. They also found that simultaneous presentation of text and illustration (i.e., both in view at the same time) promoted better memory of the verbal text, while sequential presentation of text and illustration (i.e., text presented first followed by supporting graphic) tended to produce better memory for the elements protrayed in illustrations. While these results suggest that graphics included within a computer-based instructional environment may be expected to increase learning, the literature regarding such applications has not advanced to the point that specific design guidelines may be derived. For the moment, designers of CAI materials must derive guidance from studies performed on static and/or non-interactive media.

Human Factors Research

This area of research, which combines information from the fields of psychology and engineering, is concerned with how to visually display information on computer screens and is of great potential interest to the CAI designer. Currently, however, the variables regarding dialogue design which have been researched focus more on textual than graphic aspects (Reilly & Roach, 1986).

Interactivity I Direct Manipulation

More sophisticated techniques are required to study the role of computer graphics in the learning process, and interactive applications require separate exploratory study. An early study conducted by Oliver (1969) to investigate the effectiveness of interactive computer graphics to teach selected methods in numerical analysis was reported by Brooks (1977). A non-randomized, pretest-posttest design was used in the study, in which the use of interactive computer graphics was found to significantly improve performance. In terms of qualitative observations, individual manipulation of the mathematical objects was found to improve perception and understanding of the objects represented. In addition it was noted that students using the interactive graphics system showed greater class participation and showed initiative in using the system in unanticipated ways.

The role of direct manipulation in learning requires further investigation, as we have little by way of research to explain its effectiveness. Nelson (1980) has proposed a "principle of virtuality," which refers to a representation of reality that can be manipulated, to describe the phenomena. Similarly, Rutkowski (1982) refers to a principle of "transparency," describing the ability of the user to apply intellect directly to the task with the tool seeming to disappear.

Research in the area of problem-solving may assist us in understanding the effectiveness of direct manipulation. Polya (1957), for example, proposes that drawing represents a means of suitably representing mathematical problems. Bruner (1966) also uses the idea of physical representation to convey mathematical principles. Researchers Carroll, Thomas, and Malhotra (1980) discovered that subjects given a problem with spatial representation were able to solve problems more quickly and successfully than subjects who were given an isomorphic problem with temporal representation. Schneiderman (1983) maintains that physical, spatial, or visual representations are easier to retain and manipulate than others, citing the success of LOGO in teaching children mathematical concepts.

The phenomena of direct manipulation involves a high level, active response from the user to the system. Within a CAI context, this implies an active involvement of the student with the learning situation, increasing the likelihood that the student will learn. Bork (1981) maintains that the quality of interaction in the design of the program ultimately determines the quality of the instructional program. The capability of direct manipulation made possible through computer graphics technology will greatly enhance current levels of interaction. A great deal of research in this area will be required, however, before we will be able to maximize the effectiveness of such interactions.

CONCLUSION

We have examined some of the emerging capabilities of computer graphics technology within the context of potential CAI applications. As well, we have reviewed the research in key relevant areas in an attempt to determine their applicability to these new graphic tools. It is a fact that we will have increasing access to presentation and response capabilities that have never before been possible. Guidelines for the use of these capabilities are not yet available, and on the basis of the current state of research in the field, we can predict that such assistance will take time in arriving. The CAI designer, however, needs to be aware of this impending shift from text-dominated lessons to graphics-oriented presentations where it will be necessary to design new and different interactions.

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