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2 Electronic Technologies, Education, and Cognitive Development*

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ABSTRACT

Taking a comparative approach to media, this chapter develops an argument about the cognitive effects of media and their role in education. In so doing, it focuses on the interplay of media forms and media content. The first theme is that because of its technical nature, each medium transmits certain kinds of information easily and well, other kinds with difficulty and relatively poorly. Second, because of its particular profile of strengths and weaknesses, a given medium is particularly suited to presenting certain kinds of subject matter in the educational process. Finally, a medium's profile also has implications for cognitive development: each medium calls upon and develops a particular set of abilities to process and produce information. As a consequence, the media—from print to audio, video, and computers—have a complementary role to play both in education and in cognitive development. This point leads to the conclusion that educational policy must not consider media in an either-or framework. Instead, we must move toward a system of multimedia education. By giving each medium—the old ones as well as the new—its place in a child's life and education, each medium will be able to make its own special contribution to a child's learning and development.

In this chapter, I make an argument, based on Greenfield (1984), about the cognitive effects of various media and their role in education. In so doing, I focus

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on the interplay between media form, media content, and media processing. My approach is comparative: the various media—print, radio (audio), tv, and computer technologies—will be considered not in isolation, but in relation to each other.

EVERY MEDIUM HAS ITS OWN INFORMATIONAL "BIASES"

A major theme is that each medium has its own biases. Contrary to the common assumption, a medium is not a neutral transmitter of information. Through the filter of its technical and formal characteristics, a medium transforms information while communicating it, emphasizing particular aspects of events and ideas, deemphasizing others. As a consequence, each medium presents certain types of information easily and well, other types with difficulty or relatively poorly.

Print

Let me explain this idea through some examples, starting with the printed word. Print is extremely good at presenting a person's inner reflections. Novels often take advantage of this characteristic in presenting the inner musings of a character. The personal essay is a literary genre that is built around this very strength. Television (or film), on the other hand, presents thought processes less naturally, with greater difficulty. As dynamic, visual media, they seek dynamic visual images to present; but the process of thinking or reflecting involves no visible movement at all: nothing "happens" that can be shown on a screen.

Audio

Radio or other audio media have their own set of strengths. For instance, they make dialogue and figurative language salient. In our research comparing the cognitive effects of radio and television, we gave children the same story presented in one of two media, radio (audio) or television. Each version had exactly the same soundtrack. We found that the children's recall of dialogue was better after the radio version than after the television version (Greenfield & Beagles-Roos, 1983, 1985). Apparently, the visual images distracted attention from dialogue, resulting in poorer recall. It is important to realize in interpreting these results that the information presented in dialogue is generally not reinforced by a visual image; rather it competes with the visual image, generally the image of the speakers themselves. For this reason, dialoque becomes more salient when presented in a purely audio form like radio. For similar reasons, it is not surprising that figurative language, the language of poetry, is also recalled better from a radio story than from a television story with the same soundtrack, at least among certain groups (Beagles-Roos, 1985; Beagles-Roos & Gat, 1983).

Television and Film

Television and film, for their part, have particular strengths in presenting action, three-dimensional space, and several things happening at once. Research findings indicate, for example, that action information is recalled better by both children and adults when a given story is presented on television rather than radio (Greenfield and Beagles-Roos, 1983, 1985; Beagles-Roos, 1985). The addition of moving images to words in depicting action may well explain the great popularity of sports on television and the expansion of the range of sports with which the television public has become involved.

In terms of the presentation of three-dimensional space, a Swiss study was designed to test the effectiveness of television in teaching children spatial information (Sturm & Jorg, 1981). Kindergarten and first-grade children saw or heard a television or radio version of a story. In the story, the main characters, three children, were faced with some spatial problems. For example, they were going to see an owl, and they wanted the owl to think there was only one of them. To solve this problem, they walked in a line, with the tallest child first, so that the shorter children were blocked from the owl's view. After seeing or hearing this story, each child was asked to act out the solutions to the problems, using puppets. More children could solve the problems after seeing the story on television than after hearing it on the radio. (The soundtracks were identical in both versions.) Television apparently made the spatial information necessary to solve the problem clearer, more salient, or both.

Exclusively verbal media such as print or radio (audio) are limited to presenting one thing at a time. To a great extent, information is presented in a linear order, one element at a time. In television or film, in contrast, different things can occur on different parts of the screen simultaneously. For instance, it is commonplace to have several actors or real-life people visible on the screen in a single shot. Carrying this potential for simultaneous information to an extreme, a film such as *Nashville* or a television series such as "Hill Street Blues" uses crowd scenes to present events from several subplots all at once. In sum, television and film, unlike the exclusively verbal medium of print, can easily present several pieces of information simultaneously.

Computers

Computer technology in general has a great strength in allowing users to interact with complex systems having multiple, interacting, dynamic variables. One way it does this is by means of the computer simulation, an interactive model of some real-world system. In addition to the simulation, the video game also represents a complex system, which a player must figure out in order to acquire skill in a particular game. Although most systems in the real world—e.g., an ocean, a forest, a city, a corporation, a country—are complex in this way, the computer is the first medium able to transmit and model this complexity to an audience.

These "biases" toward the presentation of particular sorts of information have implications both for education and for cognitive development.

A MEDIUM'S INFORMATIONAL "BIAS" HAS IMPLICATIONS FOR EDUCATION

In terms of education, the informational strengths of a medium mean that each medium is particularly good at presenting particular subject matter. For example, audio, because it makes figurative language and dialogue salient, should be particularly effective in presenting poetry and drama.

Television or film, because it presents action and transformation so naturally and so well, is particularly suited for presenting scientific topics, for just about all science has to do with some form of action, whether it be transformation or movement. In biology, it might be the growth of a plant; recall here the traditional science films that take slow processes of growth and speed them up on film. In physics, any experiment in mechanics will involve movement of some sort.

Computers are natural for any subject that involves teaching about a complex system. A computer simulation can allow the learner to interact with the kinds of systems that would be relevant to social studies or history—a government or a battle, for example—or the kinds of systems that would be relevant to science—such as an ecological system.

A MEDIUM'S INFORMATIONAL "BIAS" HAS IMPLICATIONS FOR COGNITIVE DEVELOPMENT

The strengths and weaknesses of each medium also have implications for cognitive development. Because of its informational "biases," each medium also calls upon and develops a particular set of abilities to process and produce information. Again, I present examples from the various media.

Print and Radio

Compared with television, print and radio seem to be relatively stimulating to the cognitive process of *imagination*. As an example, my research group did a study comparing radio and television in this respect. Again we used two versions of the same story, a radio version and a television version, each one having the identical soundtrack. This time we stopped the story a little bit before the end, and we asked the children to continue the stories. Our measure of imagination was how

many novel elements were introduced into the continuation. An element was considered novel if it had not appeared in the stimulus story just heard or seen by the child. We found that the story continuations were more imaginative following the radio presentation than following the television presentation (Greenfield, Farrar, & Beagles-Roos, in press).

This pattern of results makes sense in terms of the design features of each medium. An audio medium, lacking visual images, leaves more to the imagination. The listener must do imaginative work to create an image of the scene from words alone. Television or film, in contrast, creates the images for you. Other research has shown that a story presented in print stimulates the imagination in the same way that audio does and, again, more so than television (Meline, 1976).

Television

But television has its own set of strengths in stimulating cognitive development. For example, television develops skill in the mental representation of space, the ability to visualize space in your mind. Salomon (1979), working in Israel, has found a whole set of skills of this type that are related to viewing and understanding television and film. Figure 2.1 presents an item from one of Salomon's tests,

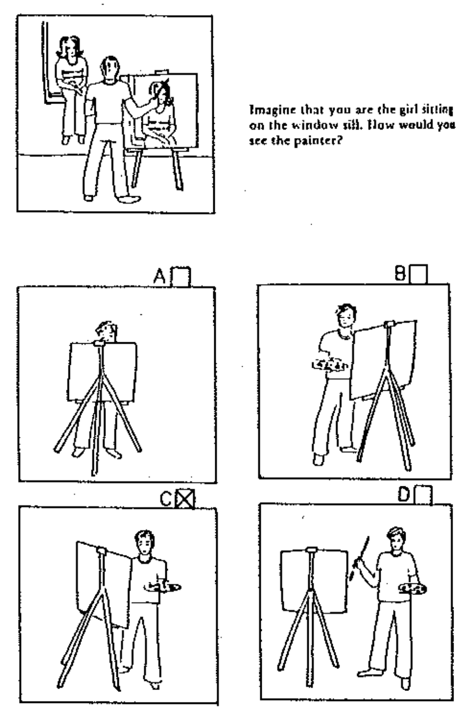

FIG. 2.1. Item from Changing Points of View Test (Salomon, 1979).

the Changing Points of View Test. At a time in Israel when "Sesame Street" was the only children's program available, Salomon found that heavy viewers of the show did better on this test than light viewers. But why should skill on such a test correlate with amount of television viewing? Salomon hypothesizes that this has to do not with the content of television, but with its technical nature as a medium and the forms that the techniques produce. A technique that is all-pervasive in television and film is to show the same scene from different camera angles, i.e., different points of view. Apparently, the effect of such repeated exposure to changes in physical points of view is to develop skill in shifting points of view in your mind, the requirement of the test illustrated in Fig. 2.1.

Such a result lends experimental evidence to McLuhan's (1964) assertion that "the medium is the message." The message, here a perceptual one, lies in a technique that is not specific to any particular type of program, but occurs in presenting almost any type of content in the medium of film or TV.

Video Games: Building Upon the Visual-Spatial Skills Developed through Television

Video games and computers can, among other things, be considered an interactive television. It turns out that many forms of computer technology build upon and utilize the *visual-spatial skills* being developed through television. Let me focus on some examples from video games, the first form of computer technology to have a mass impact on the socialization process.

The first example illustrates how the ability to mentally shift points of view is also required by some video games. Figure 2.2 shows two screens from a computer game called Tranquillity Base. In this game, the task is to land your spaceship safely on some flat terrain. At the beginning of the game the player sees a picture on the screen of the spaceship at a distance. The small size of the spaceship conveys this distance information. As the spaceship gets closer to the terrain where it must land, the point of view shifts to a close-up perspective on a part of the landscape. This perspective shift is conveyed by the relatively larger size of the spaceship. In order to be successful, the player must be able to understand the shift in point of view from the long-shot to the close-up.

My hypothesis is that children who have been socialized with a lot of television and film will be very familiar with two-dimensional representations of shifting points of view and that this familiarity then gives them a head start in understanding the screen displays of a game like Tranquillity Base. Although Tranquillity Base is a game for home computers, the requirement to shift visual point of view is found in a number of arcade games as well, so the visual experience in question is generally available.

The visual skills developed by television and film are not limited to two-dimensional representations of shifting points of view, but are, in fact, quite diverse. Figure 2.3 presents another such example. This is an item from another

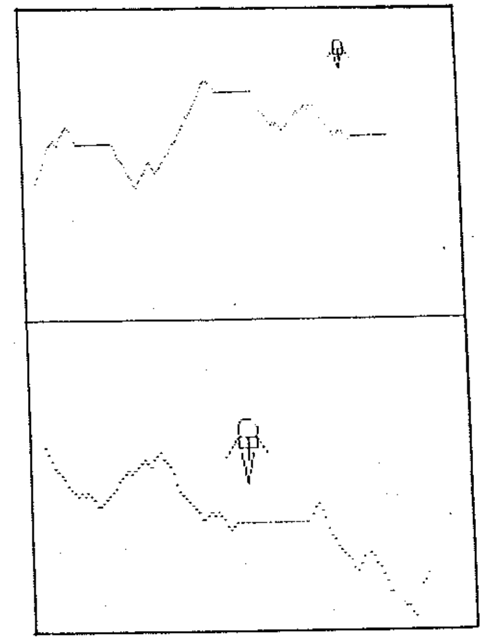

FIG. 2.2. Two screens from Tranquillity Base (Stoneware).

test of Salomon (1979), the Space Construction Test. In this item, the task is to put the four picture fragments together so that they form a room. Salomon found that children who did well on this test were better able to understand edited films than children who did less well.

Why? Again, Salomon hypothesized that the answer lies in a visual technique that is intrinsic to the film and television media. When a three-dimensional space, such as a room, is filmed, the camera does not and cannot reveal the whole space in a single shot. Instead the camera pans or cuts from one part of the room to another, showing but one fragment at a time. To have a sense of the whole space, the viewer must mentally integrate the fragments, constructing the room for himself or herself. Apparently, learning to interpret and integrate the fragmentary shots in a film creates a cognitive skill which then transfers to this paper-and-pencil test.

A number of video games require this cognitive process of spatial integration. Figure 2.4 shows three screens from a game called Castle Wolfenstein, which utilizes this skill. The goal of Castle Wolfenstein is to escape from the Castle, which represents a Nazi prison. The Castle consists of a series of mazes, only one of which is visible at a time. Yet the mazes are interconnected vertically by stairways (e.g., top right-hand corner of top maze) and horizontally by doorways (e.g., top middle of middle maze). In order to have an overview of the whole

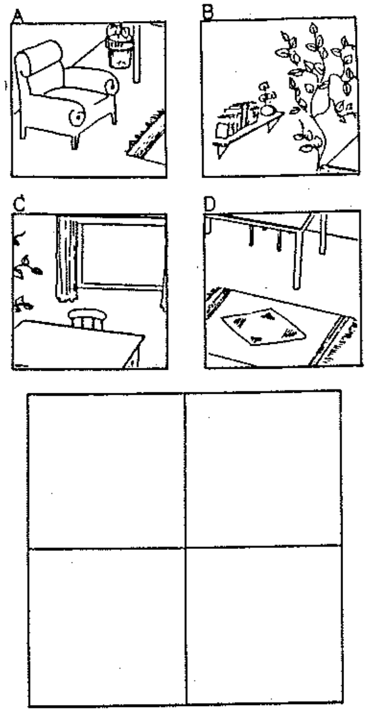

FIG. 2.3. Item from Space Construction Test (Salomon, 1979).

castle, the player must mentally put together the individual mazes and construct the space.

My own experience in playing the game indicates that this is not a skill to be taken for granted. After my first session with the game, I assumed each maze was independent of the others and that the order of mazes was essentially random. I had not only failed to integrate the fragments, but failed to realize that the fragments *could* be integrated. My son's amazement at my ignorance ("Most people realize *that*, even if they are not paying attention!") gave me a clue that spatial integration may be a well-understood convention, as well as a habit, for expert game players like him more than for other people.

The important point for present purposes is that the need to integrate fragments of space into a single structure in the video game Castle Wolfenstein closely parallels the task of the Space Construction Test, performance on which was found to be related to an understanding of film. Thus, socialization by the visual media of television and film may again provide informal training that is relevant to understanding the screen displays of video games. There is evidence that the games further develop the spatial skills which they require.

Gagnon (in press) found that giving Harvard College students 5 hours of arcade-game play improved performance on standardized paper-and-pencil tests

of visual-spatial skills. The positive effect of video game play was, however, found exclusively among inexperienced players (for the Guilford-Zimmerman Spatial Orientation Test) and among women (for the Guilford-Zimmerman Spatial Visualization Test). In fact, there was a great deal of overlap between these two groups, for the majority of women in the sample were classified as novice players, the majority of men as experts.

Furthermore, the two groups, novices and females, for whom the experimental game experience made the biggest difference, also started out with lower scores on the visual-spatial tests, so the games served something like a remedial

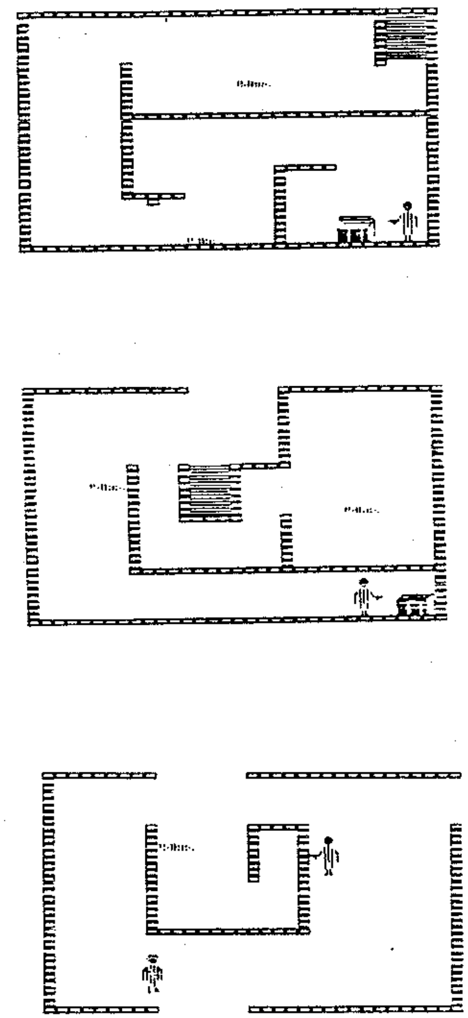

FIG. 2.4. Three interlinked mazes from Castle Wolfenstein.

function for people with relatively undeveloped spatial skills. Indeed, Gagnon found that scores on the visual-spatial tests were generally correlated with amount of past game experience: the more experienced the player, the better the performance on the test.

Visual-Spatial Skills, Computers, and Technological Education

The particular tests that were affected by video game experience in Gagnon's experiment are considered to measure factors that are important for mechanical occupations, engineering, and architecture. Recent research has gone one step further, suggesting that all sorts of computer skills are quite dependent on visual abilities.

For example, a surprising finding about word processing was that the best predictor of how easily novice adults would learn to do it was their spatial memory (for arrangements of objects) (Gomez, Bowers, & Egan, 1982; Gomez, Egan, Wheeler, Sharma, & Gruchacz, 1983). Young children picked up programming LOGO better if they were able to shift visual perspectives at the outset (Roberts, 1984). Here, a visual-spatial skill that is part of television and film literacy is relevant not merely to playing video games, but also to computer programming.

In a 1977 article in *Science,* Ferguson pointed out that the language of technology is basically a nonverbal one and that people involved in technology need to be able to think in terms of visual images. He criticized engineering schools for their bias toward educating students to analyze systems using numbers rather than visual images, pointing out that this bias has produced a lack of people who have skills to deal with real machines and materials.

Ferguson's point has applicability way beyond engineering now that so many different kinds of learning and work are being done on a computer screen. Our educational system ignores the visual requirements of the new technologies in both teaching and testing. It is concerned about print literacy, but not about visual-spatial literacy. Until this situation changes, television and video games can provide informal education in this important domain.

Learning to Deal with Complex Systems

In addition to presenting visual stimuli that demand interesting spatial skills, a video game is also a *complex system* that must be mastered. Let us take as an example Tranquillity Base, the computer game previously discussed. This relatively simple game involves six variables. In order to land the spaceship safely, the player must take account of altitude, horizontal speed, vertical speed, direction, amount of fuel, and horizontal location. These are the *multiple variables.* In addition, all the variables *interact* with each other: The effect of one variable

differs depending on the values of others. For instance, running out of fuel has a very different effect depending on whether you are on the ground or 5,000 feet up in the air. This is an example of a simple interaction between the two variables, amount of fuel and altitude. In order to land the spaceship safely, the player must take account of the variables not only one at a time, but also as they influence one another. Note too that the variables are *dynamic* because their values are changing over time. For example, fuel is constantly being used up and either horizontal or vertical position must always be changing.

Learning to deal with complex systems having multiple, interacting, dynamic variables is a significant accomplishment because the world is not a simple system, but rather many complex and dynamic systems. As we shall see in the next section, video games, although not always presenting realistic models of real-world systems, do foster skill in figuring out how a complex system works, skill that can transfer to figuring out the workings of a more realistic simulation.

Video Games and the Process of Inductive Discovery

Perhaps the most interesting point about the video game as a complex system is that no one tells you its rules in advance. The rules must be figured out by observation, trial and error, and a process of hypothesis testing.

Let me begin with an example from Pac-Man. When I first played Pac-Man, I was terrible at the game. I assumed that my reaction time was simply too slow, but thought I basically understood the game. Then I read a book called *The Video Master's Guide to Pac-Man* (Sykora & Birkner, 1982) and discovered that I had missed about 90% to 95% of the game! The game had a myriad of rules and patterns programmed into it that I had not realized existed, let alone tried to figure out. At this point, I had my first realization that even the simplest of video games (like Pac-Man), far from being simple-minded, were extremely complex and offered many cognitive challenges.

I shall present one example of a rule-bound pattern built into Pac-Man that is not explained to a player in advance, but, when discovered, will help in playing the game. Basically, Pac-Man must clear a maze of small dots, avoiding monsters. During play, the monsters, who are each a different color, come out of their corral at the center of the maze and move around. What is not obvious, however, is that each of the monsters has its own behavior pattern. One, for example, is very slow and unaggressive. Another is fast and aggressive to Pac-Man. Knowledge of these patterns can aid a player in avoiding the monsters, a key element of successful play, but they must be empirically induced through observation and trial and error.

Note the parallel to the precomputer game of chess; there, too, each piece (the rook, the bishop, etc.) has its own rules of allowable behavior. There is a major difference, however: In chess, the player is told the rules in advance; in Pac-Man the player must figure them out for himself or herself. This process of making observations, formulating hypotheses, and figuring out rules through a trial-and-error process is basically the cognitive process of *inductive discovery*. It is the process by which we learn much about the world, and at a more formal level, it is the thought process behind scientific thinking and discovery. If video games function to train this process, it would have great educational and social importance.

Video Games as Informal Training in Scientific Thinking

To test this idea, we did an experiment to document this inductive discovery process in the course of video game mastery and to see whether video games could function as a method of informal training for scientific-technical thinking. Details of the study can be found in Greenfield and Lauber, 1985. Our experiment involved using the game of Evolution, an arcade-style game for Apple computers, as an experimental treatment. Each of the treatment conditions included 2½ hours of playing Evolution.

Because video games are widely considered to have little if any redeeming social value in themselves, we were particularly interested to see if the processes of inductive discovery that they engage might transfer to problem solving in a scientific or technical context, an area of undisputed social importance. We therefore developed two parallel transfer tasks, one given as a pretest, one given as a posttest; these involved demonstrations of the operation of electronic circuits presented schematically on a video screen.

Subjects were told nothing about the demonstrations, not even that what they were seeing were circuits; they were simply told to watch carefully so that they could answer questions later about what was going on. After every few demonstrations on the screen, subjects were given written questions to answer. The questions were such that the subjects had not only to understand what they had been shown on the screen, but also to generalize their conclusions to new instances of circuits.

Our results showed that there was indeed a carry-over from video game practice in the experiment to the posttest that involved *scientific-technical thinking*. Novice game players improved significantly from pretest to posttest after 2½ hours of playing Evolution. A control group of novice players who were not given an opportunity to play Evolution did not, in contrast, show any change in test performance from pretest to posttest. A group of expert game players was also tested. They tested as high on the pretest of scientific-technical problem solving as the novice players did after their experimental treatment. This result shows that video game play in the real world may have an effect similar to that of our experimental treatment.

One puzzling question is why our expert game players, after hundreds of hours of play, did not do better on our test of scientific-technical thinking than

novices after 2½ hours of play in our experiment. Although our results show value in video games as informal training for scientific discovery processes, this limitation of the effect suggests a law of diminishing returns; a relatively small quantity of practice or mastery of a single game produces as much effect on scientific thinking as hundreds of hours of play on many different games.

Other Aspects of Computer Technology: The Example of Word Processing

There are a number of beneficial effects of word processing. At this point, however, we do not know exactly why word processing is effective. Most probably it relates to ease of revising and the motivational value of always having a clean, printed copy of your work.

Perhaps, also, word processing is an instance of learners benefiting from the availability of multiple representations of a subject area. A consortium including IBM has recently developed a successful multimedia approach to reading instruction called "Writing to Read" (Evans, 1985). In this program, word processors are just one of the media tools available to young children for coding and decoding the written word. Indeed, the most reliable finding in the area of media and education is the superiority of multimedia over single-medium instruction.

Educational Favoritism Toward Print: It is Not the Only Kind of Literacy

In education, we have, by and large, acted as though print were good at teaching everything, as though it were a "transparent" medium that simply revealed a subject without imposing any of its own distortions on the subject being presented. I hope that by now it is clear that this assumption is not correct. Print has its own set of strengths and weaknesses, just like any other medium, and these cause it to "distort" some subjects, while presenting others more accurately and easily. Like other media, it transforms information while it transmits it.

Nevertheless, our bias toward the use of the printed word in education is so strong that we have actually equated reading and writing with education. This is understandable historically, because formal education originated as a way of transmitting print literacy.

Television and Film Literacy

But literacy is not just something required by reading and writing. Just as we learn to decode the written word, we also must learn to decode other media, television and film for example. These media have their own code too. Most interesting here is the code of visual editing or montage techniques. Each technique has its own meaning, which must be learned (Andrew, 1976; Rice, Huston, & Wright, 1982; Salomon, 1979). For example, a cut between shots indicates a new perspective on the scene; a dissolve or a fade is a cue that time or place has changed; a split screen denotes an act of comparison. Understanding these conventions of the code is parallel to understanding the sounds communicated by the alphabetic code in reading. As in reading, such understanding constitutes basic literacy in film and TV. A conscious awareness of the nature of the code and how it creates different effects constitutes a still higher level of literacy skills in these media.

The idea of computer literacy is also becoming accepted, although no one is sure exactly what it involves. However, this tentative acceptance shows an opening in society toward the idea that the printed word is not unique in requiring and fostering literacy skills.

Each form of literacy has its own function and its own value. Print literacy (reading and writing) is not the only worthwhile literacy in education. Indeed, I would present the shocking hypothesis that print has become "educational" not because of the intrinsic qualities of the medium, but simply because the printed word is used in education. That is, printed material is made the subject of discussion and analysis; and students are made responsible for mastering its content (Greenfield, 1985).

My argument is that the same processes of discussion and analysis can be applied to television (and to other electric and electronic media). Indeed, there is a body of evidence, summarized in Greenfield (1984), showing that discussion of televised material with a teacher in a classroom setting enhances learning above that resulting from simply viewing the program alone. We need to remove our prejudices against television and bring it into the educational process in a number of ways, if its full educational potential is to be realized.

One such way is through analyzing the forms of television and film (such as the editing techniques discussed above) in the classroom. This treatment would be analogous to the treatment of literature that is now commonplace in English classes. This kind of study would make learners more conscious of the language or code of television and film, and would take them to that higher level of literacy.

CONCLUSIONS: THE CASE FOR MULTIMEDIA EDUCATION

The biases of each medium are such that each differentially utilizes particular cognitive skills. Not one but many media are therefore necessary to socialize and educate a well-rounded and balanced individual, a person who can relate to the world of visual images as well as to the world of words, who can figure out a complex system or imagine the setting of a novel, who can process linear inputs or comprehend several things happening at once. This is one important argument for multimedia education.

Multimedia education would also give a more equal chance to students who learn best through different modalities. Similarly, it would give a more equal chance to students who arrive at school with unequal background experience with certain media, such as the world of print. This is another line of argument for multimedia education.

From the point of view of information transmission, each medium presents a different point of view on a topic by selectively emphasizing different kinds of information in its particular representation. If multiple representations and multiple points of view are best, then multimedia methods are required. This is another argument for multimedia education.

Indeed, educational thinking about the computer (and new media in the past) has focused too much on either-or questions of media selection: Should computers replace books, or even teachers? My argument is that each medium (the teacher most of all) has its own distinctive contribution to make to education and to cognitive development and that the media should be used in complementary fashion in a process of multimedia education.

For all these reasons, we should move toward a system of multimedia education in which audio, video, and computer technologies will surely play a key role. By giving each medium—the old ones as well as the new—its place in a child's life and education, each medium will be able to make its own special contribution to children's learning and development.

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3 Learning Programming Languages: Research and Applications

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ABSTRACT

This chapter is concerned with the study of how novices learn computer programming. Four research issues addressed in this chapter are (1) users possess many misconceptions of machines and procedures, (2) learning to program involves building a concrete model of the system, (3) successful learning depends on the availability of prerequisite cognitive skills and knowledge, and (4) learning to program may be a vehicle for teaching students about their own thinking processes. Research findings and applications are described for each of these issues.

INTRODUCTION

During the past 10 years, we have been engaged in a research program aimed at understanding how novices learn computer programming (Bayman, 1983; Bayman & Mayer, 1983, 1984; Dyck, 1986; Dyck & Mayer, 1985; Mayer, 1975, 1976, 1979, 1980, 1981, 1985; Mayer & Bayman, 1981; Mayer & Bromage, 1980; Shneiderman & Mayer, 1979; Shneiderman, Mayer, McKay, & Heller, 1977). The purpose of this chapter is to summarize four of our research findings and to describe possible applications for each.