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ABSTRACT

This paper presents a historical overview of visualization as a human problem-solving tool. Visualization strategies, such as mental imagery, pervade historical accounts of scientific discovery and invention. A selected number of historical examples are presented and discussed on a wide range of topics such as physics, aviation, and the science of chaos. Everyday examples are also discussed to show the value of visualization as a problem-solving tool for all people. Several counter examples are also discussed showing that visualization can sometimes lead to erroneous conclusions. Many educational implications are discussed, such as reconsidering the dominant role and value schools place on verbal, abstract thinking. These issues are also considered in light of emerging computer-based technologies such as virtual reality. (Contains 17 references.) (Author/JLB)

Title:

Visualization as an Aid to Problem-Solving: Examples from History

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Visualization as an Aid to Problem-Solving: Examples from History

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This paper presents an historical overview of visualization as a human problem-solving tool. Visualization strategies, such as mental imagery, pervade historical accounts of scientific discovery and invention. A selected number of historical examples are presented and discussed on a wide range of topics such as physics, aviation, and the science of chaos. Everyday examples are also discussed to show the value of visualization as a problem-solving tool for all people. Several counter examples are also discussed showing that visualization can sometimes lead to erroneous conclusions. Many educational implications are discussed, such as reconsidering the dominant role and value schools place on verbal, abstract thinking. These issues are also considered in light of emerging computer-based technologies, such as virtual reality.

The increased availability of multimedia tools in education permit the design of instructional systems that incorporate unlimited variations and forms of textual, visual, aural information for both presentation and feedback. However, our sense of vision arguably represents our most diverse source of information of the world around us (Sekular & Blake, 1985). Society, including education, transmits tremendous amounts of information in visual form. Visualization is most frequently used in instruction in the presentation of information. However, visualization techniques are also powerful problem-solving tools, though they are rarely promoted as such in learning and instruction. This is unfortunate, as history is full of fascinating examples where visualization has been one of our most important arsenals of problem-solving tools (Koestler, 1964).

The purpose of this paper is provide a historical context for current efforts by instructional technologists to exploit the full potential of visualization techniques, especially those that tap the computational and graphical power of the computer. This paper will present a variety of cases where people have used visualization techniques throughout history to solve a wide range of problems. The term visualization is used broadly here to include all nonverbal cognitive strategies, including mental imagery. In addition, some counter examples will be discussed to show how visualization can sometimes lead us astray. The paper will conclude by discussing the implications of visualization in education and instructional design. These issues will surely increase in importance and complexity as highly-visual computer-based systems continue to evolve, such as in the case of virtual reality. This paper suggests that history might be able to help us as we struggle for the most appropriate applications of visualization in education both now and in the future. This paper begins with a few general examples that illustrate the role of visualization in human problem-solving at the everyday level.

Visualization as a General Problem-Solving Strategy

Although historical examples of famous people using visualization to solve complex problems are often the most dramatic, everyday people using the same visual skills to solve everyday problems are the most poignant. Some problems, of course, are inherently spatial. Consider giving or getting directions to an unfamiliar part of town. It is interesting how often the "direction giver" usually starts with a pure verbal description, but then quickly reverts to visualization "tricks" extemporaneously (such as pointing in the air to illustrate the many turns and distances). It is almost as if the person is going on a brief, imaginary trip to the final destination on behalf of the lost individual in the hope to show, by example, how to get there. The "direction getter" is at the same time trying to mentally form a visual imprint of the trip while memorizing key verbal labels (such as landmarks and street names).

Researchers who study the problem-solving process have long recognized visualization as a problem-solving tool (Finke, 1990; Finke, Ward, Smith, 1992). People often times forget to use such inherent capabilities, perhaps because schools tend to emphasize verbal skills over visual skills and abstract reasoning over concrete reasoning. Unfortunately, the idea of using simple visualization as a cognitive strategy to help ourselves solve a problem is often times either overlooked or discouraged. For example, consider the following problem (from Bransford & Stein, 1984):

> A man had four chains, each three links long. He wanted to join the four chains into a single, closed chain. Having a link opened cost 2 cents and having a link closed cost 3 cents. The man had his chains joined into a closed chain for 15 cents. How did he do it?

Take a few moments to try to solve the problem before reading ahead for the solution. As you do so, reflect on the strategies that you are using to solve the problem.

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Most people find the problem very difficult to solve mentally. The first possible solution of four links opened and closed would cost twenty cents. For most people, a good first step is to draw the four chains on paper — to construct a visual representation of the problem's entry conditions. After working through opening and closing links with a visual model, one discovers that the solution rests in opening all three links of one of the chains. These three links can then be used to join the other three chains. When the problem is converted into visual form, the solution is easy to derive.

Lave (1988) has described the ways everyday people solve problems by exploiting all of the resources present in the problem situation. For example, people were presented with an everyday problem of fixing food for three people when the recipe listed amounts for four people. One recipe called for two thirds cup of cottage cheese. One person quickly solved the abstract problem of finding "three fourths of two thirds" by first measuring out two thirds cups onto the table, patting it into a circle, and marking a cross on it. The person then removed the one excess quarter and was left with the correct portion! Lave's work is often cited by proponents of situated cognition (e.g. Brown, Collins, & Duguid, 1989), though these examples also show how everyday people use spatial and concrete reasoning abilities to grapple with problems often expressed in abstract form in traditional mathematics. The concrete solutions are just as sophisticated and complex as those expressed abstractly, yet such a visualization strategy would probably not be allowed by most math teachers.

Here is another example that aptly demonstrates the power of visualization in problem-solving (Norman, 1988). Even more so, it reveals the power of the human perceptual system to deal with problems efficiently and effectively when presented in visual form. The problem is a simple math strategy game for two players. The game starts by writing the numbers one to nine on index cards — one number per card. The nine cards are laid out on a table with the numbers facing up. The players then take turns choosing a number. Each number can only be chosen once in a game. The first player who gets *any* combination of three numbers that add up to 15 is the winner. The game is quite a challenge even for adults. One must anticipate appropriate combinations of three numbers summing to 15, while also anticipating possible winning combinations by their opponent. Numbers are chosen either to advance one's own hand or to block an approaching win by the opponent. Try playing this game a few times with a friend before reading further.

Playing this game in the pure mathematical form described above is quite difficult. Many adults do not remember ever playing this game, though most find it strangely familiar. The reason for this is that the game has another, more familiar form — tic-tac-toe. The commonalty of the games can be recognized by carefully arranging the nine numbers so that all vertical, horizontal, and diagonal combinations of three squares add up to 15, as illustrated in Figure 1 (this special combination is also known as a "magic square.") Strategies from one version of the game quickly transfer to the other. For example, capturing the middle square or the number "5" gives the player a distinctive advantage. Most adults consider tic-tac-toe to be a simple child's game not worth playing anymore because the game will inevitably end up in a draw once both players understand the "secret" to successfully blocking the opponent at every move. Interestingly, the pure math version of the game remains a challenge even knowing that it is a "disguised" version of tic-tac-toe. The point is that the game becomes "childish" only when the perceptual ability of pattern recognition is used. The game itself has not changed, only the cognitive tools used by the individual to play it.

Visualization by Scientists and Inventors

Some of the most fascinating accounts of human problem-solving show remarkably simple examples of how visualization coupled with imagination led to brilliant discoveries and flashes of insight (Burke, 1985; Shepard, 1988). It is interesting that we often refer to these people as "visionaries," somehow being able to see what others cannot. The use of this description may not be as metaphorical as one might first think. It is stunning how many scientists and inventors placed a great deal of importance on the nonverbal in the act of creative imagination. Many describe the phenomena of sudden "illumination" where solutions just "showed themselves" or came to them in sudden bursts of insight. Indeed, many famous scientists describe grasping a solution instantaneously and as a whole, and then having to face the arduous task of putting the idea already completely conceived into an appropriate verbal form to share with others. Although this section does not pretend to present an exhaustive and comprehensive account of visualization by scientists and inventors, the few examples that follow make a convincing point about the value of visualization in cognition.

Albert Einstein's unique methods of wrestling with the most puzzling problems of physics, such as light taking on characteristics of both particles and waves simultaneously, are among the most well-known. Einstein was known for using "thought experiments" to work out problems in a uniquely nonverbal manner. Perhaps his most famous thought experiment was imagining what it would be like to ride on a beam of light. This allowed him to make the conceptual leap of "seeing" light as though it were in static form. This helped him to resolve the paradoxes underlying what was to become his Special Theory of Relativity. In another example, he imagined how two people would describe the behavior of a light flashing inside a moving truck if one person was riding in the truck and the other was standing on the street to help understand the absolute nature of the speed of light.

The German chemist August Kekulé is another scientist famous for his reports of imagery. He often described how atoms appeared to "dance before his eyes." He is said to have discovered the ring-like molecular structure of benzene by gazing into a fire and seeing in the flames a ring of atoms looking like a snake eating its own tail. His accounts of problem-solving through dreamlike visual imagery are echoed in the case stories of many other scientists, including Isaac Newton.

Roger Shepard (1988) offers one of the most interesting and detailed discussions of how famous scientists and inventors have been predisposed to visualization in their acts of creative imagination and discovery. Beyond those of Einstein and Kekulé, Shepard describes the creative inventiveness of dozens of famous scientists, such as: Michael Faraday's

8	1	6
3	5	7
4	9	2

Figure 1. A "magic square:" All number across, down, and diagonal sum to 15.

visualization of the lines of magnetism; Nikola Tesla's invention of the self-starting induction motor; Omar Snyder's solution to the containment problem of uranium in the Manhattan project; James Watson's conception of the double-helix shape of DNA; and Richard Feynman's invention of "Feynman's diagrams" for use in quantum electrodynamics. A curious similarity of many of these famous thinkers is that they were often able to grasp their solutions instantly as a whole.

Based on his investigations, Shepard described a "composite caricature" of individuals who have reported extraordinary instances of visual-spatial creative imagery. Three commonalties can be found in these people's early formative years. Many were kept home from school in their first years and had limited contact with peers of their own age. Many were below average in verbal ability, such as language development. Finally, most were fond of engaging in play with concrete physical objects, such as blocks, cubes, and mechanical models. Most of these skills, abilities, and strategies were developed apart from the educational systems of their day.

Shepard goes on to suggest some provocative implications of this composite profile of a highly creative, nonverbal thinker. Working in private without much contact with formal educational institutions (such as schools), these people are likely to engage in unorthodox and nontraditional thinking which, unfortunately, may be met with disapproval or punishment in a traditional classroom. These individuals are more likely to engage in concrete visual imagery, instead of the more abstract, verbal strategies commonly promoted in the schools. Consequently, these people are likely to bring the unique human competency of spatial intuition and manipulation to bear on a problem. Finally, the dominance of visual imagery in problem-solving is more likely to trigger the motivational and affective forces thought to be more aligned with visual elements of the human psyche.

Shepard also discusses some of the educational implications of his research on the creative imagery of famous scientists. Not surprisingly, he criticizes traditional education for failing to promote visually-based creative tendencies in children. As children, the scientists he studied equated learning with becoming "engrossed in a direct, interactive exploration of such objects and events..." and were "unconstrained by conventional, verbalized, and rigidly compartmentalized interpretations..." (p. 181). He suggests education must find a way to nurture creative imagination without sacrificing formal education, though the two often appear to be in direct conflict with one another.

Other Examples

This section briefly considers the historical value of visualization as an aid to problem-solving from very diverse areas of inquiry. These examples are presented in chronological order beginning with the Cholera epidemic in the mid-1800's and ending with the new science of Chaos, an emerging field of study in which people and computers work together in partnership through scientific visualization.

The Cholera Epidemic of London in the mid-1800's. One of the classic examples of how visualization aided human problem-solving was Dr. John Snow's plotting of cholera deaths in the mid-1800's on a map of London. The obvious clustering of deaths around the Broadstreet water pump, as shown in Figure 2, sufficiently convinced authorities to remove the pump's handle even though a direct link had not been made between the disease and a contaminated water supply. Within days, the epidemic in the London neighborhood ended (Tufte, 1983).

Wilbur Wright's Wing-Warping System. The story of the invention of the airplane contains many interesting insights to design and technology. One simple example aptly illustrates the role of everyday visualization and imagination. Controlling an airplane in its three-dimensional environment (i.e. pitch, roll, and yaw) was one of the most difficult problems the Wright Brothers and others faced. The Wrights had already successfully used a rudder to control yaw and an elevator to control pitch, but were having much difficulty controlling the plane's yaw (i.e. the motion along the axis going through the fuselage from the plane's nose to tail). Wilbur Wright solved this problem of human-controlled powered flight by seeing the remarkable "wing-warping" system used by the Wright Brothers' Flyer I at Kitty Hawk while holding and twisting an inner tube box in his bicycle shop in Dayton, Ohio. Moolman (1980) writes:

> Then one day in the latter part of July 1899, while Wilbur was alone in the bicycle shop, a customer came into buy a new inner tube. Wilbur chatted with the customer awhile, idly toying with the empty inner tube box before throwing it away; as he talked he realized that he had absently twisted the ends of the narrow cardboard box in opposite directions. When the customer left, Wilbur tore off the ends of the box and saw in his mind's eye a pair of biplane wings, vertically rigid yet twisted into opposing angles at their tips (p. 112).

Plate Tectonics. It was long believed that the earth's continents had remained in their general positions immediately after the surface of the earth cooled, even though the vertical shape of the land masses had been subjected to dramatic changes, as evidenced by finding dried-up sea beds in the mountains. However, some peculiar facts puzzled scientists. For example, identical fossil evidence was found on the east coast of South America and the west cost of Africa. These were explained in various ways such as migratory animals who used now submerged land bridges. Other evidence, such as striking geological similarities, were much more difficult to explain away.

In 1915, Alfred Wegener, a German meteorologist, proposed a different solution (Burke, 1985). He noticed how

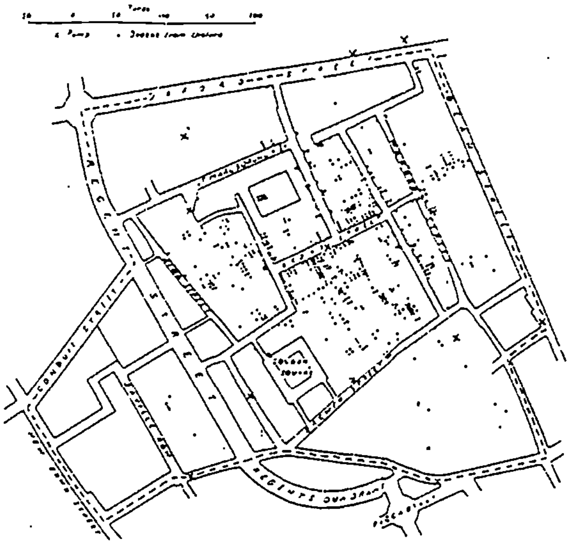

Figure 2. The famous dot map of Dr. John Snow plotting the cholera deaths in London in relation to neighborhood water pumps. This map provided strong evidence that the water in the Broad Street pump was contaminated.

many of the outlines of the continents seem to fit together like a giant jigsaw puzzle, the most dramatic example being how the east coast of South America seemed to fit the west coast of Africa. Perhaps, he suggested, at one time there was one large land mass which eventually broke apart. At the time, Wegener's proposal was ridiculed by geologists. The idea of continents drifting through solid rock seemed ludicrous. It was not until about 50 years later that Wegener's visual solution was accepted based on the discovery of mid-ocean ridges and evidence of sea floor spreading. Rock samples increase in age proportionally to the distance in which they are taken away from the mid-ocean ridges. Also, evidence indicates that the earth's magnetic field apparently changes direction every few hundred million years or so. Since rocks maintain their magnetic "finger print" it is possible to correlate the ages of rock with their inherent magnetic direction. When sections of the sea floor are mapped using this magnetic evidence, magnetic "stripes" appear on each side of mid-ocean ridge showing that sections of the sea floor alternate in their magnetic direction. As molten rock emerged from the mid-ocean ridges and cooled, it captured the earth's magnetic direction at that geological period of time. Current theories now accept that the earth's crust is made up of distinct plates that "float" on the earth's mantle. Wegener elegant solution was based on the most visual of available evidence.

Armor Plating of World War II Aircraft. A very practical example of visualization's role in problem-solving comes from World War II. A novel strategy was used to better armor combat planes. The bullet holes on returning aircraft were plotted on crude pictures of the planes. Using this information, it was determined to add armor to planes in places *other than* those indicated by the bullet holes. The idea was that since it was assumed that the planes were all hit more or less at random, the planes that did *not* return must have been hit in vital places not marked on the picture (Wainer, 1992).

The Science of Chaos. Some consider computers as the tool by which the world will be turned into a mechanized and inhuman place to live, but a contrasting view considers the computer as our liberator by performing the tedious, routine tasks poorly suited to humans and freeing us to more fully realize our potential. This collaboration between people and computers is perhaps best illustrated in the founding of the new science of Chaos, which is the study of nonlinear systems (Gleick, 1987). Such systems, though seemingly random and haphazard on the surface, actually have a hidden order lurking below. The universe is inundated with such systems, though some of the best examples are from the everyday world, including the weather, flags waving in the breeze, ribbons of smoke, and dripping water faucets. Even human problem-solving is believed to be a nonlinear system. The study of nonlinear systems has only been made more accessible with the advent of computers. The patterns of complex, nonlinear systems often only show themselves when the raw data is converted into visual form. The innate human ability of pattern recognition in combination with the computer's forte of working through millions of iterations with complex data structures have allowed many of the mysteries of chaotic systems to be explored and better understood.

One of the most interesting examples is fractal geometry, where a pattern repeats itself to infinity, such as the figure known as the "Sierpinski gasket" shown in Figure 3. This figure is created through an astonishingly simple set of rules (Michael Barnsley, as cited in Gleick, 1987, referred to this as "The Chaos Game"). The game starts by drawing three "game dots" on a piece of paper (such as those at the three corners of an equilateral triangle). Another dot, call this the starting dot, is drawn at random on the piece of paper. Then, randomly choose one of the three game dots (such as by throwing a die). Next, carefully draw another dot at the midpoint between the randomly chosen game dot and the starting dot. This midpoint now becomes the next starting dot. Finally, repeat this procedure for thousands of trials. Although the rules of the Chaos game might lead one to expect a random collection of dots on the paper, a "hidden order" emerges when the numeric information is converted into a visual form — the Sierpinski gasket.

Of course, few people are willing to invest the time or energy necessary to the play the Chaos game (and its many variations). That is where the computer comes in. Computers are wonderfully equipped to handle the tremendous number of accurate calculations necessary in the chaos game whereas people are wonderfully equipped to interpret the visual patterns that emerge. The science of chaos represents a powerful partnership between people and machines by letting each do what they do best.

Visualization Gone Awry: Some Counter Examples

It seems only fair to consider some examples of where the powers of visualization actually worked against some people.

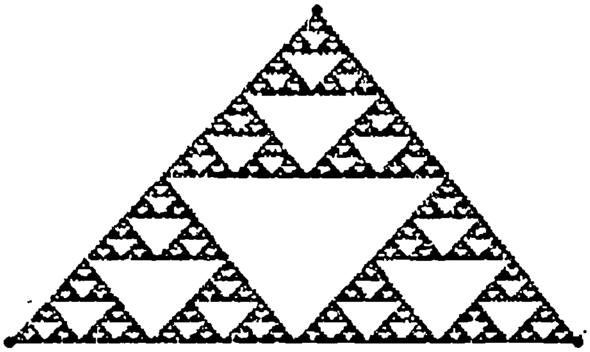

Figure 3. The Sierpinski Gasket: This fractal geometric figure repeats itself to infinity.

Visualization, like perception, is not like a camera objectively capturing images on film. Interpretation and understanding are continually filtered through one's entire knowledge, values, and beliefs. People often see and imagine what they *want* to see and imagine. Visualization, like any cognitive process, is greatly influenced by prior knowledge. Two examples are presented here where visualization led to erroneous conclusions. The result of one example led, however briefly, to wide pandemonium, excitement, and fantastic stretches of the imagination — Percival Lowell's report of seeing artificially constructed canals on Mars. The repercussions of the other example, in contrast, dramatically changed the world forever — Columbus' voyage to find a westward route to China and India.

Percival Lowell was a prominent astronomer at the turn of the century (he founded the Lowell Observatory in Arizona). Lowell became interested in the planet Mars based on early observations in 1877 by Giovanni Schiaparelli that showed some interesting fine lines on the Martian surface (Ronan, 1983). Lowell subsequently studied the planet in the early 1900's using the most sophisticated telescopic equipment available at that time. Lowell, like Schiaparelli, also observed the peculiar long crossing lines on the Martian landscape. Lowell became convinced that these were the remnants of canals constructed by some ancient civilization. The purpose of the canals, Lowell inferred, was a desperate attempt to bring water down from the polar caps to the desert-like continental areas. Unfortunately, the "canals" turned out to be an optical illusion. This example is a classic case of jumping to conclusions based on initial and ambiguous evidence, known by cognitive psychologists as "top-down processing" — initial information triggers an early interpretation against which all subsequent information is judged. This is an important psychological mechanism that helps us to find order and organization in an otherwise chaotic environment. Of course, sometimes it works against us. This same phenomena produces people's tendency to see dead presidents in fluffy white clouds.

The story of Columbus is not as amusing or innocent, if only because his adventures changed forever the global view of the world. The intent here is not to discuss the details of his trip or its ramifications, but simply why Columbus chose to make it in the first place. It seems that the most compelling reason Columbus dared to risk such an expedition is simply that he greatly underestimated the size of the earth coupled with a dramatic misconception of what proportion of the earth consisted of water and land (of course, we should not forget how important the potential wealth and fame figured in his decision-making as well) (Dor-Ner, 1991). Had he accepted an accurate account of these two facts, it is almost certain he and his sponsors would have felt the trip impractical and foolhardy at best and impossible at worst.

Historians believe that Columbus' views were heavily influenced by the writings of Marco Polo, Pierre d'Ailly, Pope Pius II, Pliny, and Ptolemy. Both Polo and d'Ailly overestimated the size of Asia considerably. The question of the earth's circumference had been a source of scientific debate for centuries, going back at least to the Greeks. The true figure is 60 nautical miles per degree of longitude at the equator. Though Eratosthenes had come close to estimating the true circumference of the earth (about 59.5 nautical miles per degree), Columbus chose figures closer to that estimated by Ptolemy (50 nautical miles). Columbus also and inexplicably downsized the figure even further, to about 45 nautical miles per degree of longitude. Therefore, Columbus envisioned a globe that was only about two thirds its true size and most of that, he thought, was covered by land. Columbus estimated a journey from the Canary Islands to Japan to be only about 2,400 miles instead of the 11,000 miles it actually is. Using this information, Columbus successfully argued his case for such a journey. The result of his journey was, of course, the accidental discovery of a new continent, though he died believing instead that he had reached islands near the coast of Asia. Of course, one could argue that Columbus used these misconceptions on purpose to persuade King Ferdinand and Queen Isabella of Spain to fund the trip as well as to find a crew even partly willing to join him. For example, Columbus admitted to falsifying information kept in the log to alleviate the crew's fears (Fuson, 1987). Even if this were to be true, Columbus' use of visualization for deception deserves equal attention.

Conclusions and Implications

The purpose of this paper has been to present some simple examples of how visualization has served as an important problem-solving tool for people throughout history. An historical context not only provides the most dramatic examples of visualization in problem-solving, but also helps to promote reflection on one of our most distinctly human abilities. Though we may never adequately understand the psychology of visualization, it will and should continue to serve as one of our most versatile problem-solving tools. Instructional designers, teachers, and all educators are therefore encouraged to consider innovative visualization strategies to nurture the creative problem-solving process. Concrete, visual solutions should not be considered inferior to those that are abstract. Of course, the two counter examples also serve to caution against unwarranted and inappropriate applications.

Despite the relatively small number of examples presented here, one soon discovers the pervasive nature of visualization in scientific discovery and invention. The examples presented here were meant only to suggest the case for the continued value of visualization strategies and should not be mistaken for an exhaustive survey. The list of examples not accounted for is, of course, large. Some domains, like geometry, are inherently spatial in nature and have their own visualization histories to tell. Some other notable examples missing from this paper include the following: Kepler's formulation of the laws of planetary motion; the discovery of chemical "fingerprints" of elements as lines in a spectrum (another good example of pattern recognition); and the spatial arrangement of the periodic table of elements. In contrast, some concepts seem impossible to visualize, such as the idea of curved space or a physical universe consisting of more than three dimensions, concepts suggested by Einstein and modern day physicists. Similarly, other historical problems, such as accurately describing the motion of a projective through space (such as cannon balls), provide interesting insights to people's attempts to visualize phenomena that have few visual clues.

There are many important implications that one can draw from this review. The trends in multimedia learning environments, especially those that are computer-based, are slowly moving from verbal to visual, from analog to digital, and from passive to interactive. The implications for the learning process are more far reaching than media dominance, however, especially when the computer's processing and graphical abilities are considered. The computer has the potential to become one of our most important cognitive tools, similar to the way paper and pencil reduced demands on human memory. Highly visual computer-based learning environments, such as *Geometer's Sketchpad* and *Interactive Physics*, allow individuals to grapple with sophisticated ideas from math and science in visual ways that are all at once concrete and intuitive. Computers and people working closely as "partners in cognition" have the potential for fundamental qualitative changes to how we view human cognition (Salomon, Perkins, & Globerson, 1991).

The implications for instructional designers are likewise exciting and challenging. Highly visual and interactive computer-based tools may allow the user to take on an unprecedented role in the design process. Rather than merely strive for learner-centered instruction that takes into account individual differences, instructional technology may be poised to let the user become a true "co-designer" of our learning environments. Similarly, some of the emerging technologies, such as virtual reality, point to design considerations that have never been asked before (Heim, 1993). Some of these are also among the most exciting, though we should be quite cautious early on. The nature of how people construct their own reality may become muddled when immersed in visually overwhelming environments. The question of whether "telepresence," the state of interacting in one location (even an imaginary one) while physically located in another, will be an acceptable state of "existence" in the future should not be casually considered. Some feel that telephones already achieve a degree of telepresence since people focus on their conversation with the person on the other end and not on the distance which separates them. Yet, when brought to the awareness level of an adult, there is no mistaking one's physical reality while using phone technology. This distinction may become blurred with the advent of virtual reality technology. This is a particularly important issue as our children begin to experience virtual reality. There is the risk that their cognitive development of reality may become confused, similar to very young children who become angry that "grandma cannot come through the phone receiver" to be with them at that very moment. Intellectual development of space and time are important issues to consider. The implications of these technologies demand attention and guidance by instructional technologists today in preparation for tomorrow.

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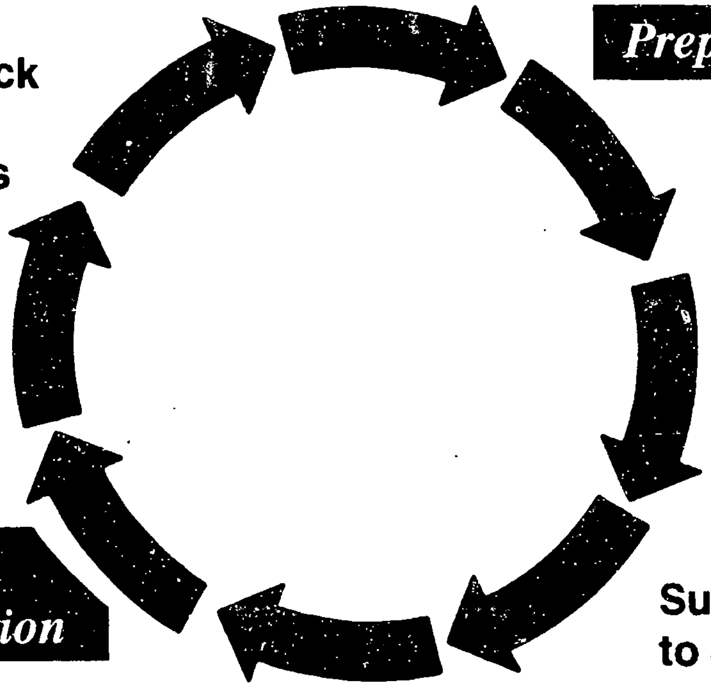
Appendix A
(Zane Berg and Mauri Collins)

Scholarship



Generation

New Ideas

Brainstorming

Prepublication

Draft

Circulate Drafts

Conference presentations

Submit to Journals

Review

Peer Review

Acceptance

Publication

Disseminate (Libraries)

Post Publication

Abstracting Indexing

Feedback from Readers

Appendix B

(David A. Goodrum, Laura T. Dorsey and Thomas M. Schwen)

Figure 1

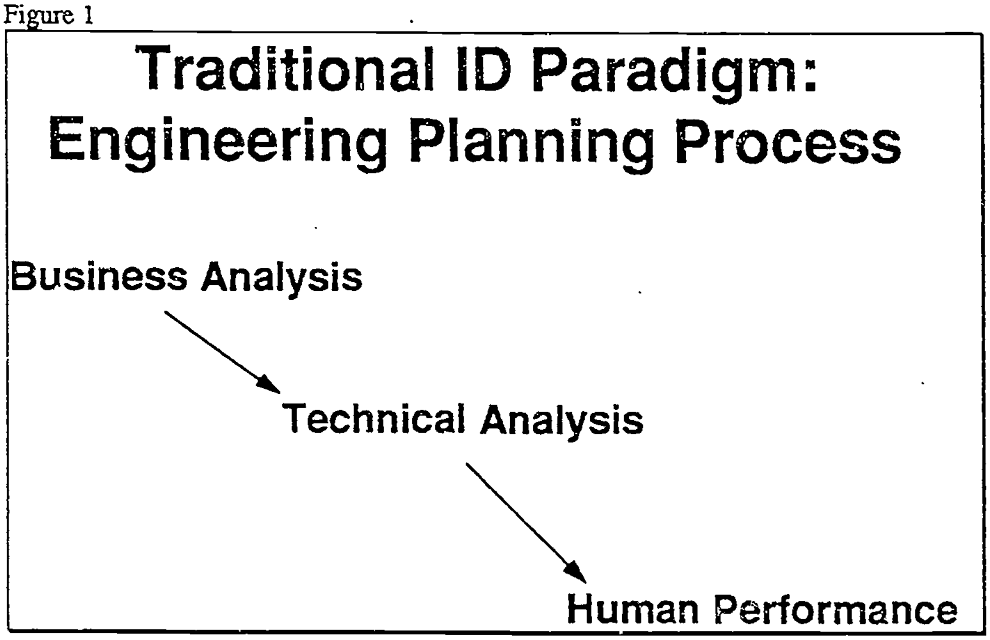
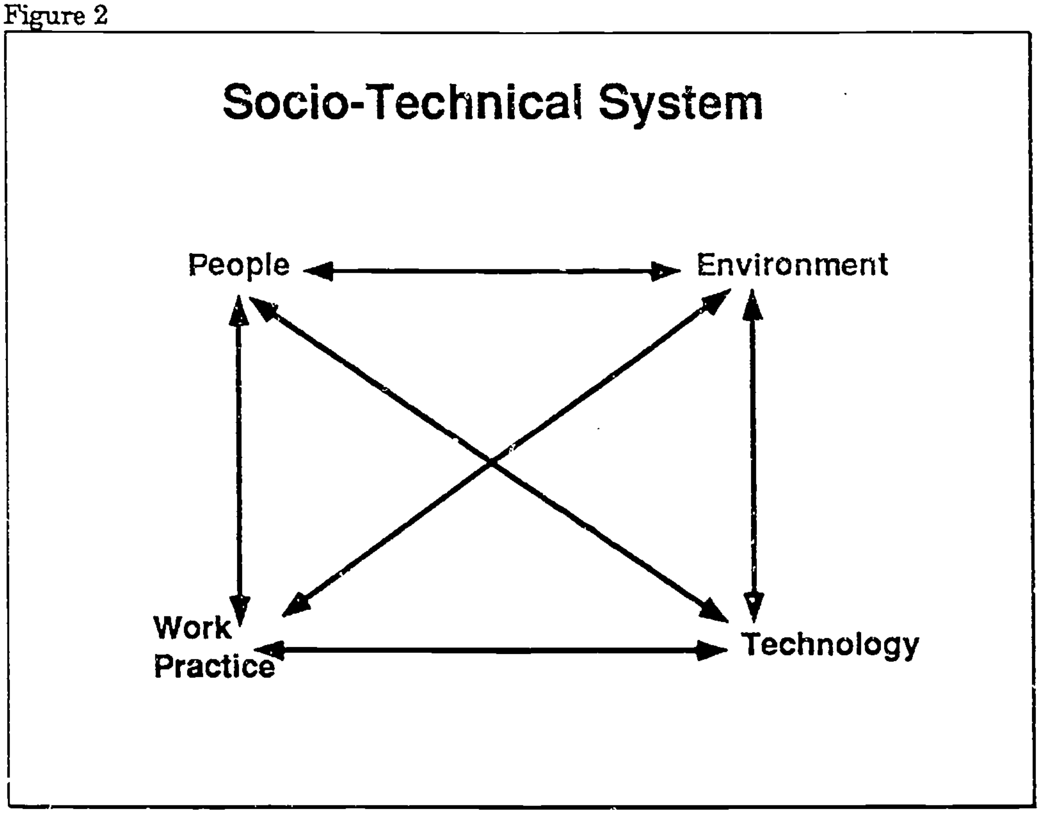


Figure 2



(Adapted from Harbour, 1992)

Appendix B

Figure 3

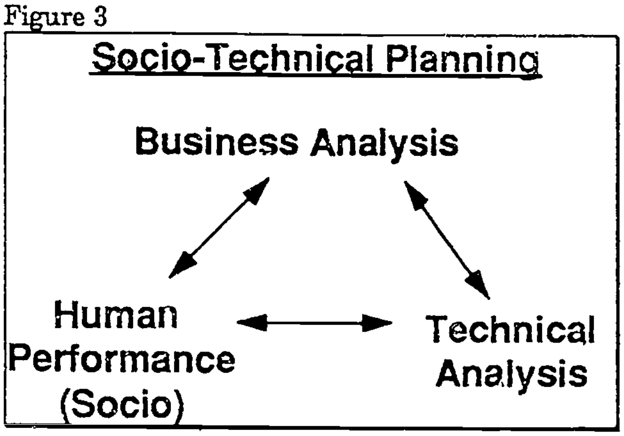


Figure 4

Participatory-Stakeholder Design Team

Roles	Contribution		
	Knowledge	**Stakeholding**	**Participation**
Customers (Direct & Indirect Users)	Organization & work practice specific knowledge	Living with the consequences of the change for tasks, jobs relationships, etc.	User representatives involved in all stages and aspects of development
Technical Community	Information skills Technological skills	Skill advancement and vested interest in the solution	Analyze, design, deliver and support information components
Training Community	Task & content analysis skills Knowledge of human learning	Skill advancement and vested interest in the solution	Analyze, design, deliver and support training/learning components
Social Systems Change Experts	Organizational analysis skills Knowledge of human adaption & interaction	Skill advancement and vested interest in the solution	Analyze, design, deliver and support organizational and social change.

(Adapted from Eason, 1988)

Appendix B

Figure 5

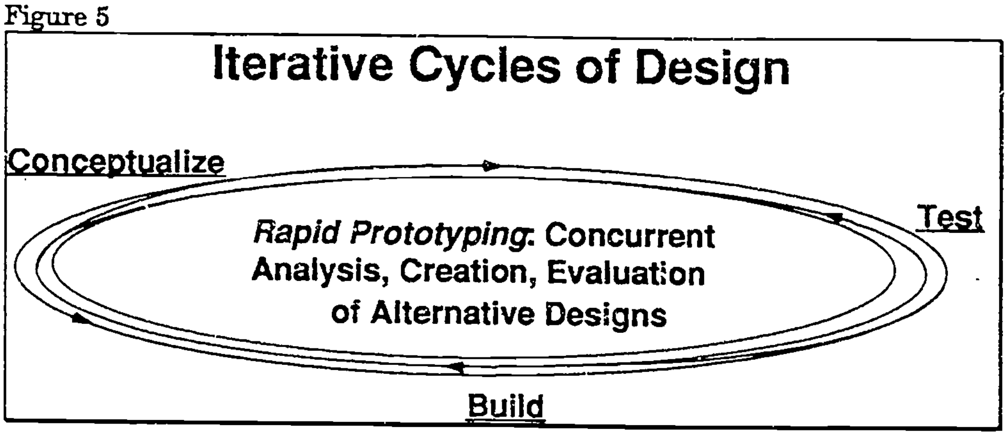
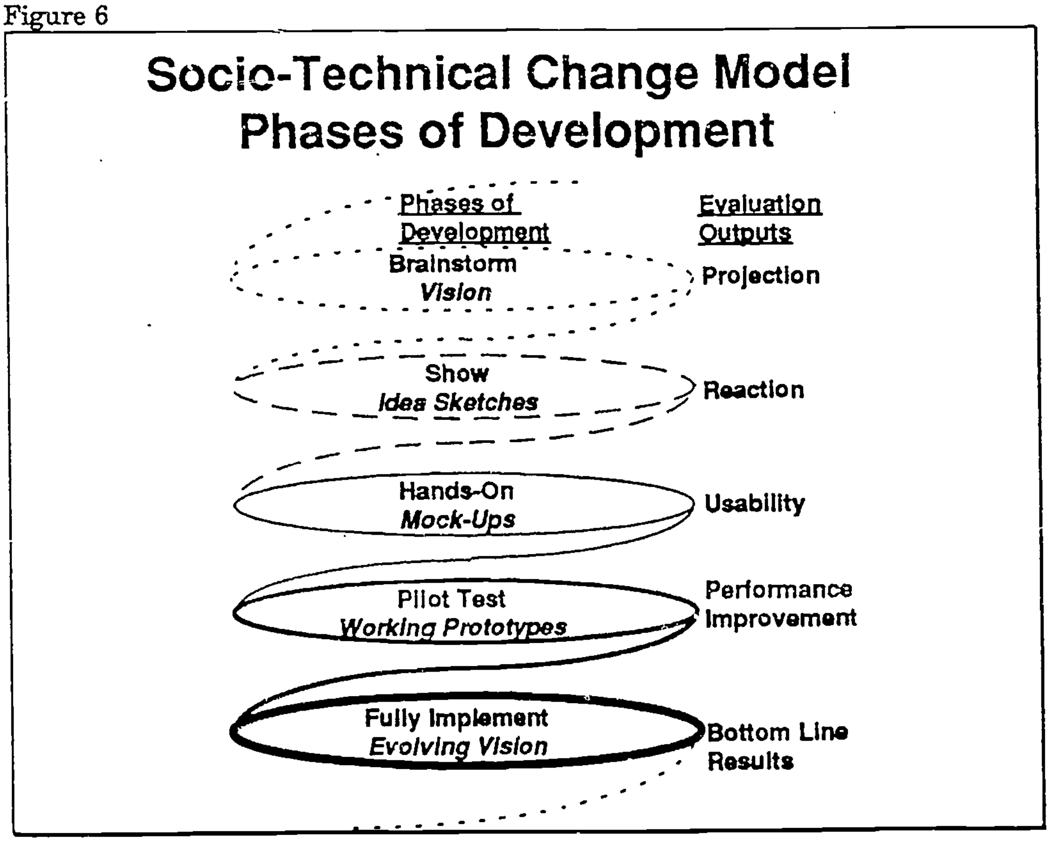
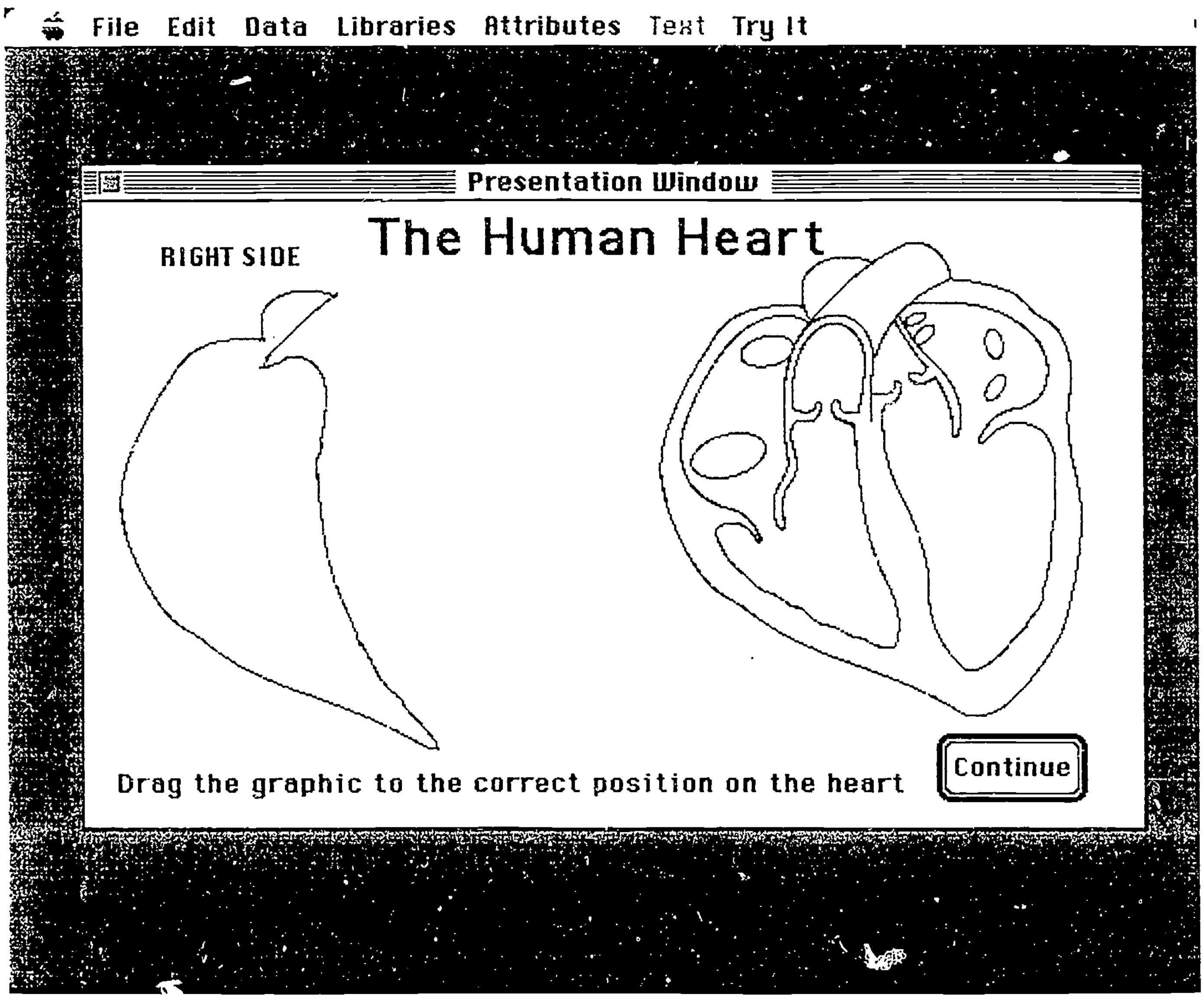


Figure 6



Appendix C

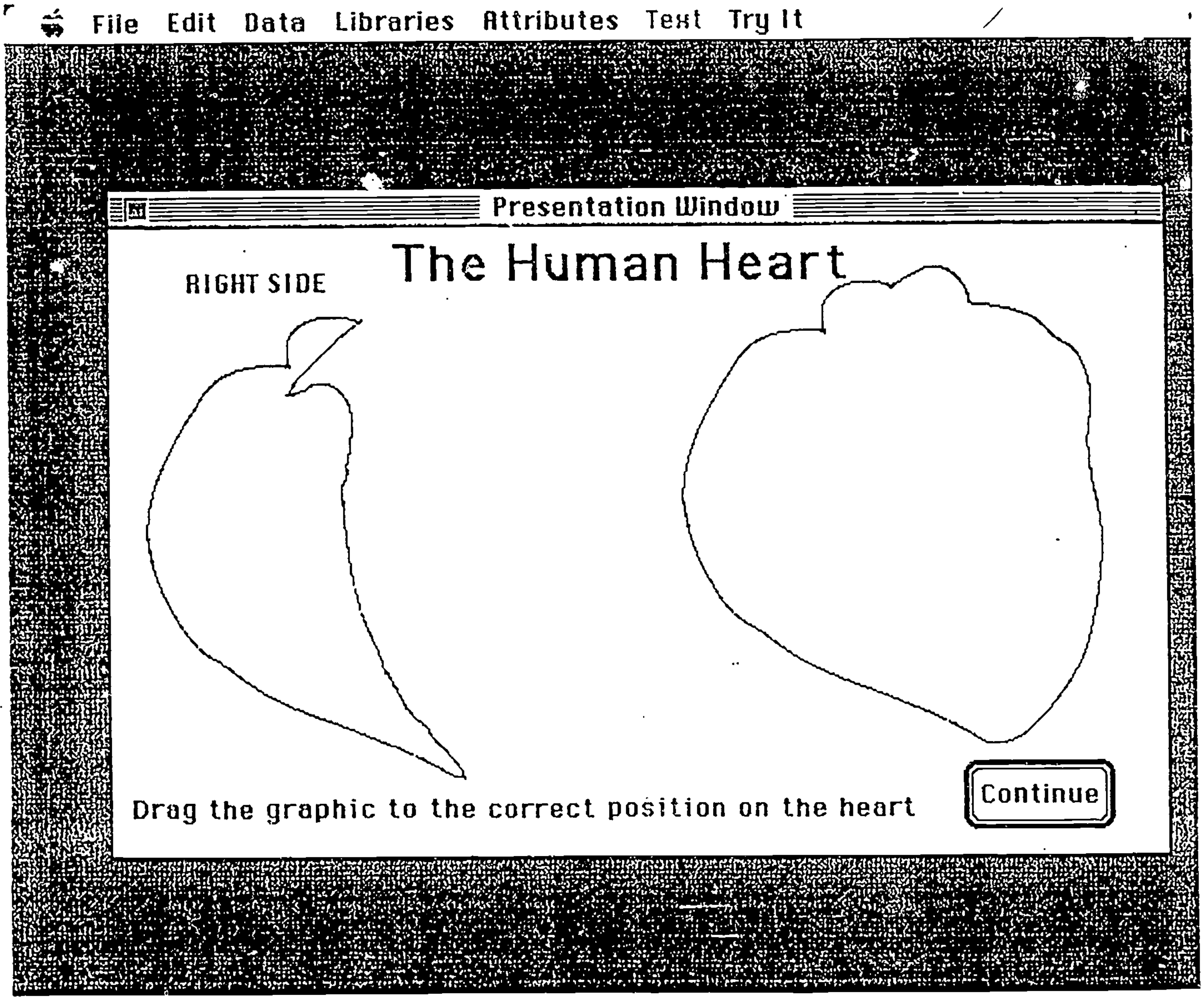
(Brenda Bannan Haag and Barbara L. Grabowski)



The Human Heart

Drag the graphic to the correct position on the heart

Appendix C



Drag the graphic to the correct position on the heart

Appendix D
(Philip A. Koneman and David H. Jonassen)

Figure 1. Sample PFNet.

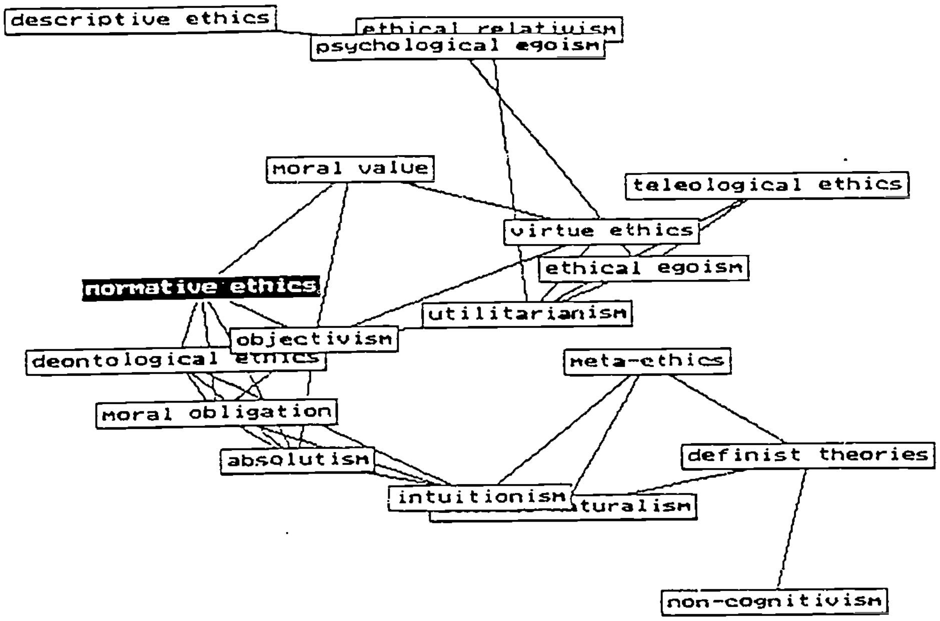
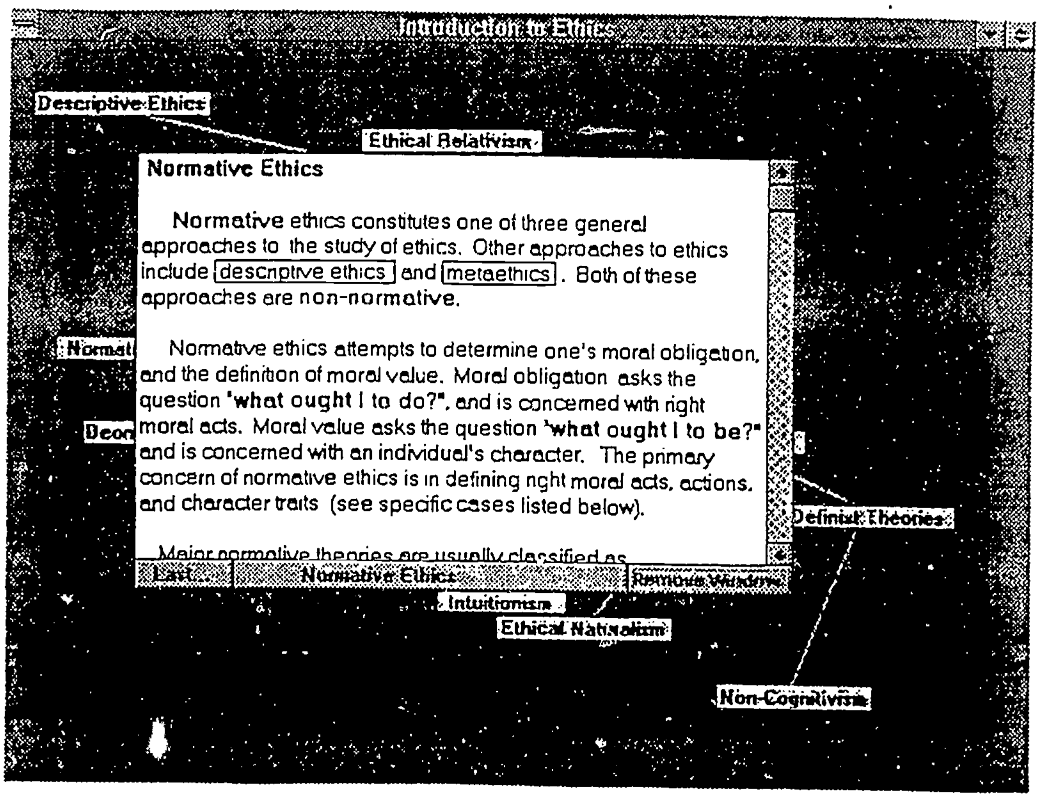


Figure 2. Text window with structured interface in the background.



Normative Ethics

Normative ethics constitutes one of three general approaches to the study of ethics. Other approaches to ethics include descriptive ethics and metaethics. Both of these approaches are non-normative.

Normative ethics attempts to determine one's moral obligation, and the definition of moral value. Moral obligation asks the question **"what ought I to do?"**, and is concerned with right moral acts. Moral value asks the question **"what ought I to be?"** and is concerned with an individual's character. The primary concern of normative ethics is in defining right moral acts, actions, and character traits (see specific cases listed below).

Major normative theories are usually classified as

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Appendix E
(Robert V. Price, Judi Repman, and David White)
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Appendix F
(Scott L. Schneberger and Karen Lee Jost)

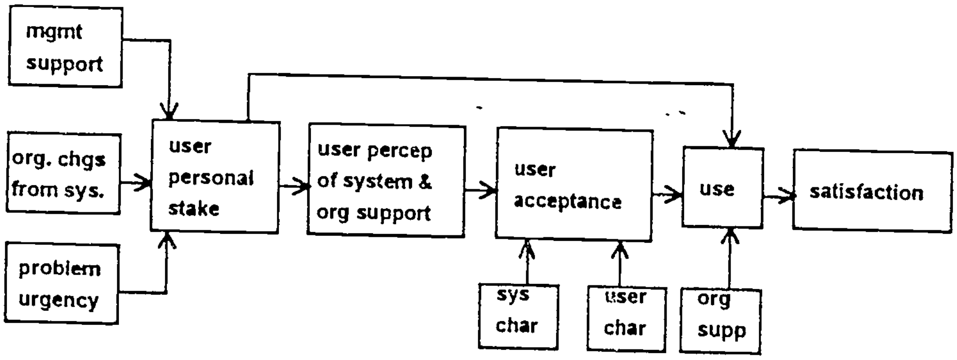

Figure 1. Information Systems Implementation Factor Model

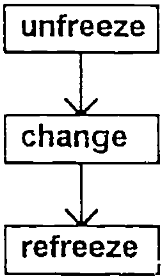

Figure 2. Organizational Imperative Model for IS Adoption and Implementation

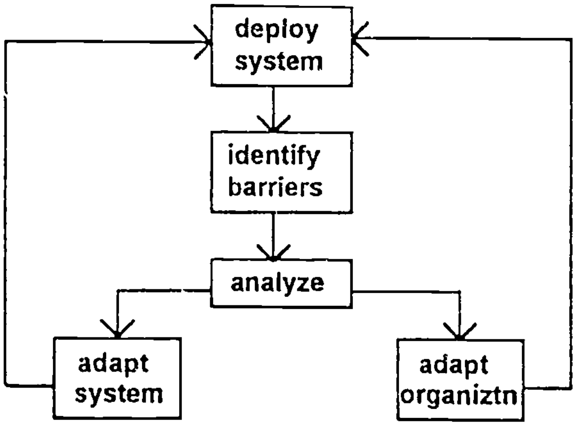

Figure 3. Emergent Perspective Model for IS Adoption and Implementation

Appendix G
(Ruth V. Small and Sueli M. Ferreira)

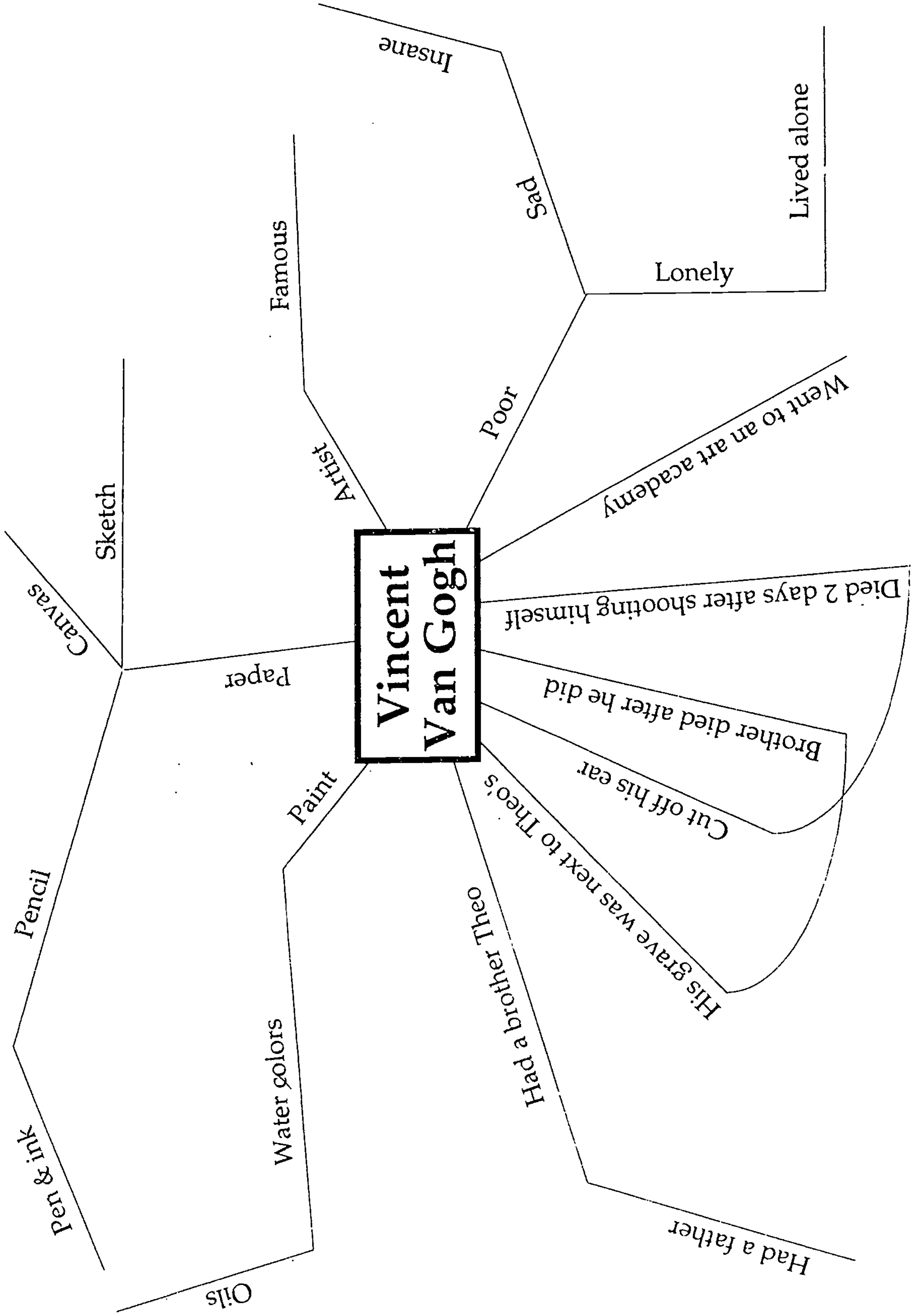

Figure 1. Sample Pattern Note

Appendix G

Group	n	Find			Engage			Extract		
		Tot	%	Mean	Tot	%	Mean	Tot	%	Mean
Pr/Ch	43	819	29%	19.0	1375	49%	32.0	599	22%	13.9****
Mm/Ch	46	2095	35%	45.5****	3851	64%	83.7****	40	1%	0.9

* p<.05
** p<.01
*** p<.001
**** p<.0001

Table 1. Information Location and Use Activities (Find, Engage, Extract) by Children in Print and Multimedia Treatment Groups

Group	n	Find			Engage			Extract		
		Tot	%	Mean	Tot	%	Mean	Tot	%	Mean
Mm/Ch	46	2095	35%	45.5	3851	64%	83.7	40	1%	0.9
Mm/Ad	35	2320	30%	66.3**	5578	70%	157.6****	23	0%	0.003

* p<.05
** p<.01
*** p<.001
**** p<.0001

Table 2. Information Location and Use Activities (Find, Engage, Extract) by Children and Adult Multimedia Treatment Groups

Appendix G

Group	n	Engage					
		Text			Nontext		
		Tot	%	Mean	Tot	%	Mean
Pr/Ch	43	758	55%	17.6	617	45%	14.4
Mm/Ch	46	978	25%	20.8	2873	75%	62.5***

* p<.05
** p<.01
*** p<.001
**** p<.0001

Table 3. Engaging Activities for Text and Nontext Information by Children in Print and Multimedia Treatment Groups

Group	n	Engage					
		Text			Nontext		
		Tot	%	Mean	Tot	%	Mean
Mm/Ch	46	978	25%	20.8	2873	75%	62.5
Mm/Ad	35	1521	28%	43.5****	3998	72%	114.2***

* p<.05
** p<.01
*** p<.001
**** p<.0001

Table 4. Engaging Activities for Text and Nontext Information by Children and Adult Treatment Groups

Appendix G

Group	n	Instr.	Total	Value	Expectancy
Pr/Ch	43	Pretest	75.5	34.9	40.5
Pr/Ch	43	Posttest	71.2	34.2	37.1
		Pre + Post Mean	73.4	34.5	38.8
		Pre- Post Change	-4.3	-0.7	-3.4
Mm/Ch	46	Pretest	79.8	37.4	42.5
Mm/Ch	46	Posttest	83.4	40.9	42.3
		Pre + Post Mean	81.6*	39.1*	42.4
		Pre- Post Change	3.6	3.5	-0.2

* p<.05
** p<.01
*** p<.001
**** p<.0001

Table 5. Total Motivation Scores, Value and Expectancy Subscale Post-Pre Mean, and Pre-Post Change Scores for Children in Print and Multimedia Treatment Groups

Appendix G

Group	n	Instr.	Total	Value	Expectancy
Mm/Ch	46	Pretest	79.8	37.4	42.5
Mm/Ch	46	Posttest	83.4	40.9	42.3
		Pre + Post Mean	81.6	39.1	42.4
		Pre- Post Change	03.6	03.5	-00.2
Mm/Ad	36	Pretest	91.0	46.1	45.1
Mm/Ad	36	Posttest	88.7	46.8	41.9
		Pre + Post Mean	89.9*	46.5**	43.5
		Pre- Post Change	-2.3	0.7	-3.2

*	$p<.05$
**	$p<.01$
***	$p<.001$
****	$p<.0001$

Table 6. Total Motivation Scores, Value Expectancy Subscale Post-Pre Mean, and Pre-Post Change Scores for Children and Adult Multimedia Treatment Groups

Appendix G

Group	n	Instr.	Total	Knowledge Levels							Knowledge Representations								
				Main			Branch				Word			Phrase			Sentence		
				Tot	%	Mean	Tot	%	Mean	Links	Tot	%	Mean	Tot	%	Mean	Tot	%	Mean
Pr/Ch	43	Pretest	315 (7.3)	146	46%	3.4	169	54%	3.9	13	172	55%	4.0	76	24%	1.8	67	21%	1.6
Pr/Ch	43	Posttest	555 (12.9)	282	51%	6.6	273	49%	6.4	33	141	25%	3.2	192	35%	4.5	222	40%	5.2
Mm/Ch	46	Pretest	353 (7.7)	186	53%	4.0	167	47%	3.6	18	214	61%	4.6	75	21%	1.6	64	18%	0.02
Mm/Ch	46	Posttest	531 (11.5)	264	50%	5.7	267	50%	5.8	31	214	40%	4.6	162	31%	3.5	155	29%	3.7

* $p<.05$
** $p<.01$
*** $p<.001$
**** $p<.0001$

Table 7. Total, Main, and Branch Terms, Linking Terms and Words. Phrases, and Sentences for Pretest and Posttest Pattern Note Scores for Children's Print and Multimedia Treatment Groups

Appendix G

				Knowledge Levels							Knowledge Representations								
				Main			Branch				Word			Phrase			Sentence		
Group	n	Instr.	Total	Tot	%	Mean	Tot	%	Mean	Links	Tot	%	Mean	Tot	%	Mean	Tot	%	Mean
Mm/Ad	35	Pretest	407 (11.6)	170	42%	4.9	237	58%	6.8	45	237	58%	6.8	152	37%	4.3	18	4%	0.5
Mm/Ad	35	Posttest	780 (22.3)*	205	26%	5.9	575	74%	16.4***	80	491	63%	14.0	246	[illegible].5%	7.0	43	5.5%	1.2
Mm/Ch	46	Pretest	353 (7.7)	186	53%	4.0	167	47%	3.6	18	214	61%	4.6	75	21%	1.6	64	18%	0.02
Mm/Ch	46	Posttest	531 (11.5)	264	50%	5.7	267	50%	5.8	31	214	40%	4.6	162	31%	3.5	155	29%	3.7

* p<.05
** p<.01
*** p<.001
**** p<.0001

Table 8. Total, Main, and Branch Terms, Linking Terms and Words, Phrases, and Sentences for Pretest and Posttest Pattern Note Scores for Children and Adult Multimedia Treatment Groups

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