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The Relationship Between Linguistic and Image Based Learning Approaches for Complex Problem Solving: A Case for Computer Generated Animation in Instructional Presentation of Complex Technical Processes

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CHAPTER I

Introduction

Nature of the Problem

Educating students about certain complex technical processes, such as electronics is an especially challenging task due to the intangible nature of the subject matter (e.g. electricity). Other areas of technical study such as hydraulics or mechanics might possibly be just as difficult if it were not for the fact that the interaction of their elements are easier to see and therefore easier to visualize. This is not the case with electricity. In order to monitor the flow of electrons in a circuit, special instruments must be utilized. In order to understand the relationship between the different elements of electronic theory the student must wade through a quagmire of mathematical formulas and abstract laws which must be learned by rote and accepted on faith until the student has had enough experience to develop full comprehension.

Visualization of processes in complex technical fields such as electronics has been an indispensable asset to physicists working in the field. Michael Faraday, one of the greatest physicists of all time, was considered a visionary not only metaphorically, but in the literal sense.

> He saw the stresses surrounding magnets and electric currents as curves in space, for which he coined the name 'lines of forces', and which, in his imagination, were as real as if they consisted of solid matter. He visualized the universe patterned by these lines - or rather by narrow tubes through which all forms of 'ray vibrations' or energy-radiations are propagated. This vision of curved tubes which 'rose up before him like things' proved of almost incredible fertility: it gave birth to the dynamo and the electric motor; it led Faraday to discard the ether, and to postulate that light was electro-magnetic radiation. Perhaps the most remarkable fact about Faraday is that he lacked any mathematical education or gift, and was 'ignorant of all but the merest elements of

> arithmetic'; and mathematics is of course regarded as an indispensable tool of the physicist. (Koestler, 1964, p.170)

With the most recent developments in computer generated animation the possibility now exists for modern day visionaries to model their insights about complex technical processes such as those involving electronics with the computer. Interaction between microscopic electrons which normally occur in a period of nano seconds can be graphically blown up and slowed down with computer animation so that the student has the opportunity to observe the chain of events that cause electricity to behave the way it does.

Statement of the Problem

Is there sufficient evidence in the literature to support the use of computer generated animation to aid students in complex problem solving? If so, how can computer generated animation assist in the instructional presentation of complex technical processes?

Purpose of the Study

The purpose of this study is to provide a rationale for development of new approaches to educating students about complex technical processes. This study may also prove helpful for determining what type of technical content is better suited for computer animated presentation.

Research Questions

1. When and how is imagery used in complex problem solving?
2. What is the role of analogies, metaphors and models in learning?

3. How can computer generated animation be utilized in the instructional presentation of complex technical processes?

Delimitations

This study involves a historical research design which will examine learning research concerning the relevancy of imagery to learning processes. This information will be foundational for determining the preconditions within the learning processes that support the validity of computer animated instructional presentations.

Limitations

Computer generated animation has only become a realistic tool for educators within the last two to three years. Few really good quality educational presentations utilizing state of the art animation are currently available to the educational market. Those that do exist are very expensive. Due to a limited time frame and budget this study will not involve an experimental test of existing computer animated instructional presentations.

Assumptions

This study assumes that sufficient evidence exist in the literature to support that imagery is relevant to learning. Secondly it assumes that evidence of the relevancy of imagery in learning is sufficient to prescribe the potential for computer animated presentation in the instructional process.

Definition of Terms

Complex technical processes: This is a cover phrase to include invisible processes such as movement of electrons in a conductor, or for abstract concepts such as the theory of relativity. Any process which might be considered complex due to the fact that it cannot be seen by the naked eye, or because it involves a unique perspective not traditionally understood by common sense (Author).

Image: A visual counterpart of an object formed by a device (as a mirror or lens). A mental picture or conception: impression, idea, or concept. A vivid representation or description (Merriam-Webster, 1974).

Linguistic: Having to do with the study of human speech including the units, nature, structure, and development of language or a language (Merriam-Webster, 1974).

Terms one through eight are relevant to the heuristic guide given in Figure 2.

1. Association: Association has to do with linear associations or sequential organization. Furthermore, associative operations are usually thought to be of a rather mechanical nature. Associative operations are not completely reproductive as in the case of "repetition."
2. Generalization: Generalization must be regarded primarily as a productive operation, in the sense that previous experience is transferred to new situations. One may also regard generalization as a sequentially organized operation; for example, through analytic deduction in successive steps from a verbal principle.

3. Grouping: Grouping implies that several elements are unified into a whole. Grouping will be regarded as a simultaneously organized operation.
4. Level of Operativity: Level of Operativity may be seen as higher in cases of repetition and association.
5. Repetition: Repetition can be regarded as reproductive and sequentially organized operations.
6. Restructuring: Restructuring is a type of transformational operation which is simultaneously organized.
7. Transformational: Transformational operations shall be regarded as operations explicitly geared to generation of novel information. Transformations may be regarded as both sequentially and simultaneously organized.
8. Type of Operativity: Going further to the left with the Type of Operativity signifies an increase in the incidence and utility of visual imagery as a consequence of facilitating the opportunity for a simultaneous representation. (Kaufmann, 1980, p.143-4)

CHAPTER II

Review of Literature

The Relationship Between Imagery, Language, and Problem Solving

Early research in the area of perceptual psychology reveals that the status of imagery or sensory content is secondary to linguistic thinking. The notion that many held was that when sensory content occurs in thought, it is not relevant to thought. This idea was expressed by Betts in 1909 and is still held more recently by Pylyshyn in 1973 (Kaufmann, 1980).

Experiments concluded in 1921 by Comstock, however, prompted him to conclude that when imagery is present as part of the content of thought, it is also relevant to thought. Comstock's method was one of presenting subjects with a simple problem which they were to solve. When the answer to the problem was given the subjects were asked to recall the experiences from which to was derived.

Imagery was reportedly used in several ways:

1. Imagery was used as material for working out the problem.
2. Imagery was used as an 'anchor' or as a way of holding on to the meaning of a problem. Imagery helped subjects to fix the central parts of a problem in some way.
3. Imagery was used to illustrate to the subject that his answer was correct.
4. Imagery was used as a regulation of the problem. Imagery functions in the correcting of a mistake, or carrying an anticipated meaning. (Comstock, 1921)

Comstock's reply to a charge of irrelevancy concerning imagery was to purposely introduce an irrelevant factor. He asked subjects to first recall pictures from experience and then asked them to solve some completion task. Some of the pictures were relevant to the task, while others were not. Comstock observed that where imagery was irrelevant, it dropped out. Where imagery was relevant and useful, it remained (1921).

Richard Feynman, Nobel prize winner in physics, reinforces this idea in his account of how he uses imagery to regulate a problem in mathematics.

> I have a scheme, which I still use today when somebody is explaining something that I'm trying to understand: I keep making up examples. For instance, the mathematicians would come in with a terrific theorem, and they're all excited. As they're telling me the conditions of the theorem, I construct something which fits all conditions. You know, you have a set (one ball)-- disjoint (two balls). Then the balls turn colors, grows hairs, or whatever, in my head as they put more conditions on. Finally they state the theorem, which is dumb thing about the ball which isn't true for my hairy green ball thing, so I say, "False!"
>
> ...I guessed right most of the time because although the mathematicians thought their topology theorems were counter-intuitive, they weren't really as difficult as they looked. You can get used to the funny properties of this ultra-fine cutting business and do a pretty good job of guessing how it will come out. (1986, p.71)

Now that it has been determined that imagery is relevant to thought when it occurs, early research on the question of what conditions arouse imagery can be examined. One hypothesis found in the research is that imagery is strongly linked to the novelty dimension in problem solving (Kaufmann, 1980).

In 1883 Galton concluded that imagery may be an important element in creative (inventive) thinking. He gives the example of a mechanician stating:

> The faculty (visualization) is undoubtedly useful in a high degree to inventive mechanicians, and the great majority of those whom I have questioned have spoken of their powers as very considerable. They invent their machines as they walk, and see them in height,

> breadth, and depth as real objects, and they can also see them in action. (1883, p.78)

Nikola Tesla, father of the A-C generator and other noteworthy inventions, claimed he could project before his eyes a picture, complete in every detail, of every part of a machine. These pictures were for him more vivid than any blue print. From this inner imagery, Tesla was able to build complete inventions without drawings. He also claimed to be able to run these machines in his mind for weeks after which he could examine specific components for wear (cited in Mckim,1980).

In 1914 Fox conducted an experiment which is also cogent to this issue of imagery. Fox's subjects were presented with several statements having to do with mathematics, history and grammar. The subjects were to reflect on the meaning of the statements and then to report, by way of introspection, the content of their minds at the time of their thinking. If imagery played a part in their thinking they were explicitly instructed to state whether the realization of meaning preceded or succeeded the occurrence of the mental image.

Fox observed from this experiment that conflict in consciousness was a favorable condition for imagery development, while the condition of smooth thinking was unfavorable for imagery production. Fox summarizes as follows:

> The experiments show that any delay or conflict in consciousness is a favorable condition for arousing mental image, that is, one that will in some way tend towards a cessation of the conflict. All the other conditions which we found to be suitable for stimulating the production of mental images are reducible to this general formula. Thus, conflict or disagreement with a suggested statement, an attempt to overcome the difficulty of understanding a proposition, suspension of judgement, doubt, emphasis or pause, all have been shown to produce mental images abundantly. And all of these are examples of struggle and delay in thinking. The experiment also shows directly that the contrary set of conditions are unfavorable to the production of images. Thorough or immediate understanding, an easily grasped concept, ready assent to a proposition,

> straightforward or unimpeded reasoning, are all cases in which as a general rule, images play no part. (1914. p.430)

In 1921 Bartlett studied the function of imagery in memory. He found links in visual imagery with the function of change in recognition. Bartlett noted that all the subjects showing marked inclinations towards inventions in their cognition relied on visual imagery. He concludes that invention, defined here as the bringing in of totally new details, is particularly prone to occur in the use of sensory imagery.

Early accounts of perceptual psychology have supported the notion of visual imagery and its relevance to problem solving. It is also evident that conflict, novelty and change are an inevitable precondition to imagery in the process of creative thinking (Kaufmann, 1980).

More recently experiments concerning perceptual psychology have focused on the relationship between visual and linguistic representations in relation to problem solving. The hypothesis being examined links imagery with the initial phase in problem solving, and for the subsequent and more familiar stages subjects turn to pure linguistic representations (Kaufmann, 1980).

In 1972 Woods performed experiments to demonstrate this pattern. He designed task for subjects which involved up to six premises, resulting in several different types of arrays. The premises all used the adjective 'taller' to make comparisons between themselves. Here is an example of a five premise problem:

1. D is taller than E
2. C is taller than D
3. A is taller than C

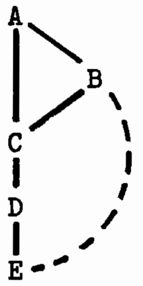
4. A is taller than B

5. B is taller than C

Who is taller, B or E?

This problem can visualized by the following diagram.

Figure 1. A five term series problem.



(cited in Kaufmann, 1980, p.137)

This array pictured here represents the relative heights. The dotted line directs us to the relation posed in the final question. Wood's experiment with the five premise problems pointed out that only subjects who had constructed a unified representation (image) of the premises were able to answer the questions correctly. In these experiments Wood was able to confirm that subjects attacked the problems through imagery in the initial phase of the problem-solving were able to develop increasing familiarity with the problems such that they were able to switch over to linguistic representation (cited in Kaufmann, 1980).

In the reporting of Wood's results in 1972, Johnson and Laird make the following comment:

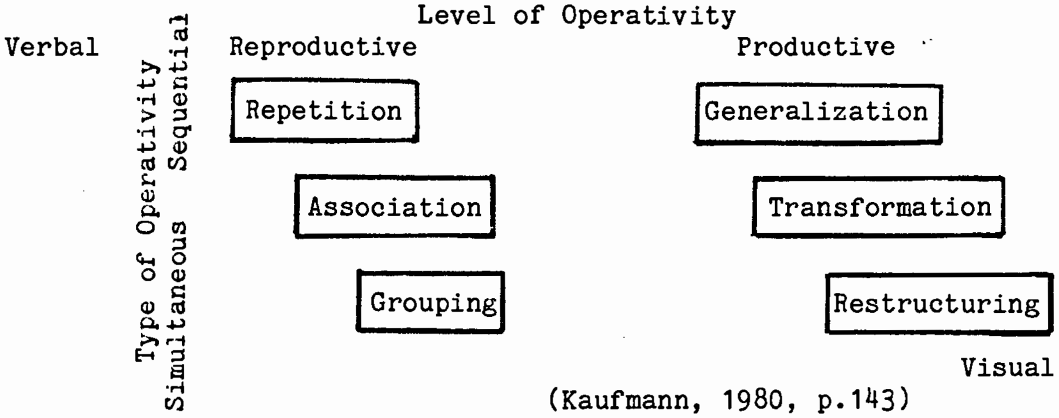
> The effect of practice is probably to induce a more mechanized approach to the problem, which minimizes effort and which is appropriate to the particular constraints of the material. At the same time such an approach is likely to be less flexible and may make it harder to solve an unexpectedly novel type of problem. (p.80)

Apparently subtle differences between visual and linguistic representation in relation to problem solving is something of a trade off.

> In face of a novel task, imagery is particularity appropriate as a representational medium. Being holistic and crude, imagery leaves the problem-solver with several alternatives which are all necessary when knowledge is scarce. With increasingly familiarity, some alternatives may be dispensed with and more exact and swifter linguistic representations may be used in tackling the problem. The price to be paid for greater swiftness and economy is the following: Since language forces standardization and constraint on the problem-solver, he will be at a loss to tackle a novel task deviating from principle implemented in the linguistic representation. With increasing complexity and novelty of the task, the utility of a pure linguistic representation decreases systematically. (Kaufmann, 1980, p.138)

The utility of verbal and visual symbolic activities will now be examined under reproductive and productive problem solving conditions. First it will be necessary to develop a rough schematic model of the kind of operations that may be involved in problem-solving task. These will be related to each other in respect to "Level of Operativity" on the "X" axis and "Type of Operativity" on the "Y" axis. This schematic should be thought of primarily as a heuristic guide of the illustration of major points of view.

Figure 2. Schematic Classification of Problem-solving operations in relation to 'Level of Operativity' and 'Type of Operativity'.



(Kaufmann, 1980, p.143)

In 1971 Paivo reported that verbal representation was superior in tasks rating high in sequentiality, (e.g. serial recall) whereas visual representation seems to be the preferred mode under conditions favorable to a simultaneous organization of information (e.g. recognition memory) (cited in Segal, 1971).

In the lower right hand corner of the table in figure 2. both high productivity and simultaneous organization are required, it is here that visual memory is the preferred mode of representation. The types of tasks which would satisfy conditions existing in the lower right hand corner are traditional insight problems. Examples of insight problems are practical construction tasks. Kaufmann explains insight problems as follows:

> In this kind of problem, the subject is usually confronted with a complex situation in which the task is one of inventing a workable construction of some sort. This is to be achieved with the aid of some concrete implements, which often have to used in unusual ways. The subject, then, has to deal with the situation as a whole (simultaneous organization) and generate novel information as to the function of the implements (high level of Operativity). (1980, p.151)

Also linked with the relevancy of imagery required to perform practical construction problems is the relationship between the solution of practical construction problems and the ability to construct pictorial analogies for the solution in question. Both Maier in 1945 and Raaheim in 1961 conducted experiments to test for the relationship between imagery, analogies, and the ability to solve practical construction problems.

Maier's construction problem involved presenting subjects with two sticks and a "C" clamp and asking them to construct something that would enable them to hang up a coat. The solution was to clamp the sticks together and wedge them between the floor and the ceiling. This left the C-clamp in a position where one could hand his coat on it. Raaheim's problem involved transporting peas from a glass on the table of an empty glass on another table two meters away. The subjects were given some newspapers, string, and scissors from which they could construct a funnel or channel through which the peas could be poured (cited in Kaufmann, 1980).

In addition to requiring the subjects to solve the problem, they were also asked to image and write down as many pictorial analogies related to the solution as possible. Results of the experiment revealed that 17 out of 22 solvers were able to develop such an analogy. These results strongly support the notion that the ability to solve practical construction problems is significantly related to the ability to develop a meaningful pictorial analogy for the solution (Kaufmann, 1980).

In 1975 Kaufmann saw that the next logical hypothesis to test would be to examine the relationship between a verbal presentation of how to solve a practical construction problem and a visual presentation. Kaufmann administered both a spatial and verbal test to subjects in order to predict their problem-solving performance. The spatial manipulation test involves a figure-rotation task wherein the subject must identify which figures are the same as the model even though they have been rotated in different positions or even reversed. The verbal ability was the WAIS Vocabulary test and the problem to be solved was the Pea Problem from Raaheim. Early results supported the hypothesis that the solvers were superior to the nonsolvers on the Figure Rotation Test. However, the Vocabulary Test revealed no significant difference between solvers and nonsolvers.

In another attempt to get more reliable results, Kaufmann employed the Sandefjord-Rybakoff spatial test as well as the Betts QMI (measuring vividness of visual imagery), and the Gordon's test of controllability and stability of visual imagery. Kaufmann's 1975 results found that scores on the spatial test significantly predicted success in problem-solving ($p<.01$ for combined score), however, neither verbal nor imaginal tests were related to problem solving (Kaufmann,1980).

Kaufmann summarizes his results as follows:

> It is seen then, that spatial manipulation test predict performance on practical construction problems consistently and significantly when the simultaneous organizing is controlled. This may be interpreted as a substantiation of the hypothesis advanced above, that visual imagery is especially suited for the execution of transformational activity needed in solving task of productive thinking. (1980, p. 157)

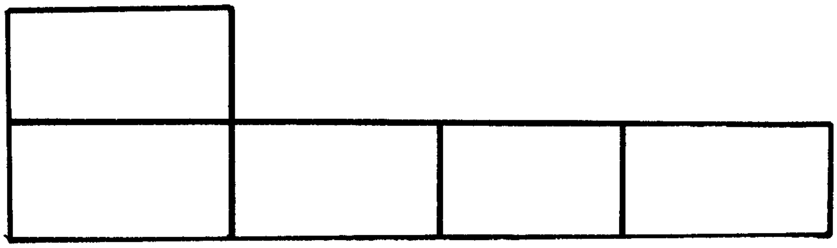
Other interesting variables relevant to the relationship between visual and verbal presentations were explored by Katona in 1940. He used what is known as match-stick problems, wherein the subject is presented with a specific arrangement of matches and is asked to restructure the initial configuration into a novel configuration into a novel configuration according to specific requirements. This test is especially appropriate since subjects are to deal with configurations (simultaneous organization) and are required to transform the original configuration in ingenious ways to solve the task (generation of novel information through the anticipation of consequences of exploratory moves.) Most specifically Kotona examined the effect of different ways of teaching his subjects to solve match-stick problems. He focused on the comparison between a verbal-rule instruction (verbal presentation) and visual demonstration of a relevant problem solving procedure.

The verbal presentation consisted of the following general principle: all sides with a single function, that is, limiting two squares at the same time, must be changed into sides with a single function, limiting one square only (Kotona, 1940, p.62).

The visual presentation subjects were shown in step-wise fashion how to solve the problem incorporating shading of squares from which no side should be removed.

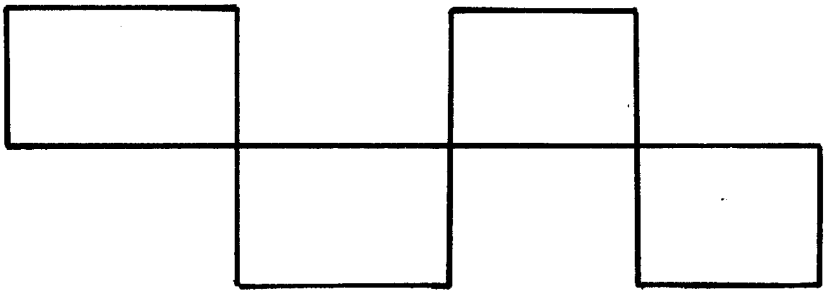
Figure 3. Illustration of Katona's Match-Stick Problem.

(1) Initial configuration



To be transformed into a configuration consisting of four squares by moving no more than three matches.

(2) Solution



(cited in Kaufmann, 1980, p.158)

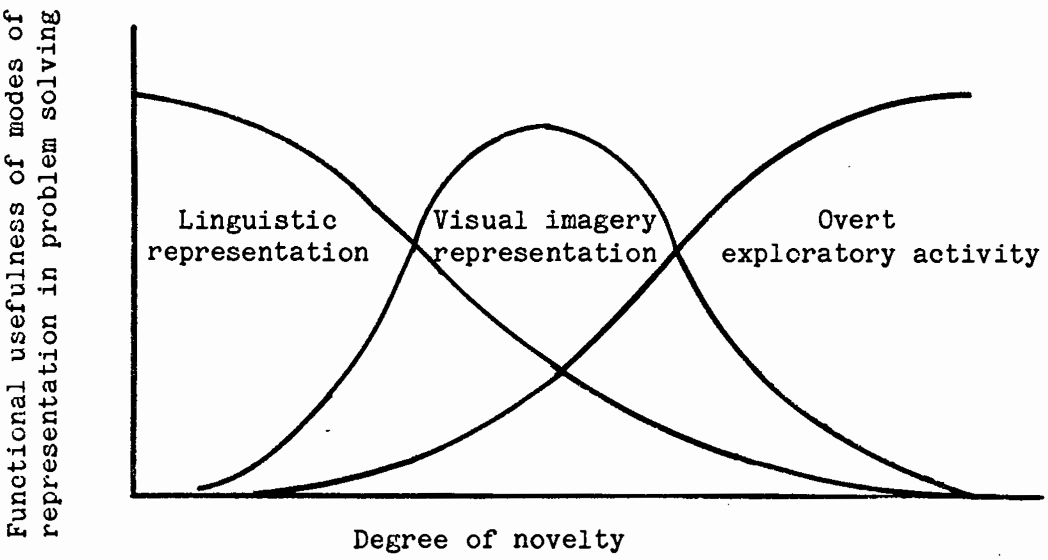
Katona's results showed that subjects receiving the visual presentation ranked superior in problem solving performance, and were capable of solving significantly more transfer-problems than subjects given verbal-rule instructions. Kotona concluded that the verbal presentation tended to trick subjects into approaching the problem in a mechanical fashion, inhibiting inventiveness in problem-solving (1940).

Perhaps now it might be appropriate to ask about a situation where the individual is faced with a totally unfamiliar task to which there is no relevant previous experience from which to draw. One possible explanation was put forth by Raaheim in 1974 when he suggested that task which transcends one's upper threshold of experience can only be solved through overt exploratory activity.

In an attempt to examine this dimension of activity, Davis in 1973 presented subjects with a switch-light problem-solving apparatus. The task involved activating switches on a response panel in order to achieve a particular pattern of lights in a matrix. Subjects were directed into two groups, one with and one without pretraining. Davis observed that subjects with no pretraining achieved the solution through an overt, trial-and-error strategy. Subjects receiving the pretraining reached the solution through a covert implicit-trial-and-error strategy. From this Davis concluded that the problem solver will think if he can, and manipulate if he must (1973, p.43).

Central to the hypothesis here is that when an individual is confronted with a totally unfamiliar task, he is in need of feedback information gained from overt, exploratory activities. (Kaufmann, 1980)

Figure 4. Functional usefulness of different modes of representation in problem-solving in relation to task-novelty.



(kaufmann, 1980, p.167)

To summarize, it can be seen from the figure that problem solving activity breaks down into three basic levels.

> Given a high degree of familiarity in the task confronting the individual, a pure verbal representation will be superior, providing for a quick, stable and generalizable problem-solving performance. As novel features in a problem-situation appear, visual imagery as a symbolic system gains greater prominence, assisting in the verbal symbolic function. As the novelty of a problem increases, there will be a corresponding increase in the need for overt, exploratory activity.
>
> In a general perspective, however, we hold the view that language is by far the most important symbolic instrument available as a tool of thought. Since language is bound up with the more conventional aspects of knowledge, is will, however, stand in need of assistance from visual imagery and overt exploratory activity when familiarity of the task decreases, and the demand for generating novel information increases. (Kaufmann, 1980, p.167)

The Relationship between Analogies and Metaphors in Scientific Discovery

> It has frequently been pointed out by psychologists who have studied creativity that analogies and metaphors are often used by scientist in making their discoveries. The origin of this conclusion is the fact that many themselves have said that they obtained their insight or illumination with the aid of an analogy. (Dreistadt, 1968, p.97)

One usually associates the use of analogies and metaphors with poetry and literature, but research reveals that they can also play an important part in the development of major scientific fields as well. Dreistadt (1968) defines a metaphor as an analogy expressed in verbal form. An analogy, however, is understood to begin in the form of sensory, usually visual, imagery.

Dreistadt breaks down analogies into a series of classifications according to experience from which they originate. His first level of classification is to see analogies as being either objective or personal. He then see analogies as being either analytic or synthetic depending on how the analogy aids in the problem-solving process (1968).

Henri Poincare, a legendary mathematician, had this to say about the relevancy of analogies:

> ...the mathematical facts worthy of being studied are those which by their analogy with other facts, are capable of leading us to the knowledge of a mathematical law just as experimental facts lead us to the knowledge of physical law. They are those which reveal to us unsuspected kinship between other facts, long known, but wrongly believed to be strangers to one another. (cited in Gheselin,1952, p.35)

The study of analogies can frequently act as a catalyst to merging one's interest from one field to another. Charles Hermite, another great mathematician, observed that other sciences, especially biology may be appropriate to study even for mathematicians since hidden and eventually fruitful analogies may appear between processes in both kinds of study. Hermite continues that a person's interests, such as reading in other fields, can become a source of analogies. It can even be the case that expanding interest into other fields might be sufficient to cause the person to actually work in them as well (Hadamard, 1945).

Robert Oppenheimer claims that "...analogy is indeed an indispensable and inevitable tool for scientific progress." (1956, p.129) Of the five examples cited by Oppenheimer for the use of analogies here is one on wave theory:

> Wave theory - it originated in the observation of regular, rhythmic changes in matter, waves on water, and was developed by easily conducted physical exploration of sound waves, where there is a periodic change, a regular change in the density of air or other media....At each point the scientist have tried to make a theory like earlier theories, light like sound, as material wave; matter like waves like light waves, like a real, physical wave; and in each case it has been found that one had to widen the framework a little, and find the disanalogy which enabled one to preserve what was right about the analogy. (1956, p.131)

James Clark Maxwell, in his study of electromagnetic theory constructed an elaborate analogy/model to account for both electrostatic effects as well as magnetic attraction and electromagnetic induction. Observe the use of analogies in his vision of magnetic phenomenon:

> He imagined a uniform magnetic field consisting of a portion of space filled with cylinders rotating at the same velocity and in the same direction about the same axes an nearly parallel. The cylinders can turn in the same direction because they do not make direct contact with each other but have rows of small spheres, like layers of ball bearings between them which act as gears. (Dreistadt, 1968, p.99)

Niels Bohr claimed that the idea of complementarity in physics was derived from the metaphor that one could not know somebody simultaneously in the light of love and in the light of justice (Gruber, 1964). He understood this metaphor from a theme found in the Bible and other areas of literature.

Einstein used analogies frequently to illustrate aspects of his principles of Equivalence of Gravitation and Inertia. He contrasted the situation of physicists inside a freely falling elevator within a skyscraper with the idea of physicists being accelerated through space inside another elevator at the speed of gravitational acceleration and observed that from the point of view of the physicists within the elevator in space, they would not be able to distinguish their sensation of falling from the sensation experienced by the physicists in the elevator within the skyscraper (Barnett, 1948).

In contrast to objective analogies, Dreistadt defines personal analogies as an analogy where the person himself is included within the analogy and makes up part of the analogy (Dreistadt, 1968). An example of a normal personal analogy would be Archimedes who discovered the technique of measuring the gold content of the crown by displacement of water in a container by accident when he observed his own body displace water in the process of getting into the bath (Koestler,1964).

In another example of a personal analogy, Einstein visualized himself as a passenger riding on a ray of light and holding a mirror in front of him. He speculated that the mirror would render no image of him since the light and the mirror are traveling in the same direction and at the same velocity with the mirror a little ahead. He continued that a stationary observer with a mirror would be able to see the reflection of both the rider and the mirror. From this fantasy Einstein showed that optical events are relative. From these analogies derived from fantasy, Einstein deducted that they explain the real world (Barnett,1948).

Analogies function as a packaged visualization. They reduce the amount of imagery required to solve a problem enabling an entire idea to come in an instant. Analogies serve as a guide, to assist in providing a path through a problem in order to solve it (Dreistadt, 1968).

CHAPTER III

Analysis of The Literature

Discussion

From the literature it has been supported that problem-solving as a process passes through three general stages. The first stage involves starting from a vague situation, totally unfamiliar to the problem solver, and requiring overt exploratory activity. The second stage is the visualization stage which provides the problem solver with a picture of the problem in his or her mind. Finally the visualization is transferred into linguistic representation where it can be quickly and efficiently retrieved when needed. As shown in the literature, this continuum of beginning a problem in uncertainty and finishing it with effective resolution is facilitated by visualization.

This process can be likened to the way computer programmers attack a programming problem. The initial phase involves problem identification where the programmer employs intensive inquiry into the cause effect relationships in the problem (overt exploratory activity). Frequently programmers draw out diagrams and flow charts designed to articulate the entire problem 'out front' so that all the subtle characteristics of the problem's solution can be charted. This is the visualization process in the area of programming, but it is not unlike the way people approach problem solving in general.

Next the computer programmer writes an algorithm which further transforms the visual flow charts into linguistic representations, until the final transformation into machine language takes place enabling the computer to perform according to the program's guidance. The finished program is now capable of accommodating huge quantities of data processing in a matter of microseconds. This capability of the computer to detect a situation, and within a moment be able to compute its significance and make the appropriate response, is the end goal of a good program. A similar goal is also the end result of a good understanding of a complex technical process.

The finished computer program, however, is only capable of responding to the precise situation for which it is programmed. The computer, without the assistance of a qualified programmer endowed with the skills of inquiry and visualization, is unable to respond to conflict, novelty, and change. People, however, are capable of responding to change by restructuring in their mind the components of the new situation and visualizing the interrelationship of the elements to make changes where necessary to accommodate a desired outcome. The role of visualization, then, is to facilitate the manipulation of images in the mind in order to hang on to all the elements of a problem long enough to allow the mind to process it into linguistic form. In a similar way the animating capacity of the computer facilitates the development and manipulation of visual images for the purpose of enabling the student to visualize the relationship among the elements in a complex technical process.

The role of analogies and metaphors can also be related to the way programmers go about writing programs. Analogies and metaphors assist in the transfer of process-oriented information from a familiar situation into a unfamiliar situation. They are like 'mental subroutines' in computer programming. Analogies link things together in familiar settings and can frequently be shifted into unfamiliar settings with a few minor adjustments and bring meaningful order to a seemingly unfamiliar problem.

A commonly utilized analogy in electronics is the use of water flowing through a pipe to represent the electrons passing through a conductive wire. It is not a perfect 'fit', but for the purpose of illuminating a students comprehension of an intangible process and providing guidance for his or her quest to 'put it all together,' such analogies are tremendously helpful. Analogies have even been helpful for this author to explain the function of analogies and metaphors themselves in terms of subroutines in computer programming. Animated visualizations employ analogies for the treatment of processes that are really not totally understood. Usually enough is known about certain processes in physics or chemistry to identify them as behaving similarly to something that is more familiar. By animating the familiar process students are given the chance to see how the same process is functioning in a different situation. For example the formation of waves on water can be shown to be identical in function to wave formation in air.

The notion of utilizing computer generated animation is not specifically related to the way computers are used in programming for the sake of solving problems in the field of mathematics or physics. The graphic potential of computer generated animation is the same as the graphical potential of traditional cel animation as it is exemplified in classic Disney productions. The computer generated animation is merely a more economical way of doing animation. The display screen can be thought of as the ultimate blackboard. It is a space outside of the mind where people can manipulate visual images and bring life to ideas that are not necessarily clear in common sense day to day experience.

Because the animation tool is outside of the mind and accessible by many, the visualization can be shared. Those who are more advanced in a technical field with the artistic ability to develop high quality animation production, will be able to recreate the same visualizations in animation for all to see, that helped them understand a complex technical process themselves. Computer animation is not something different than visualization. It is merely the canvas, the tool on which those who visualize well can demonstrate their vision for others.

Frequently the visual elements in animated sequences of complex technical process are not the exact representations of the object they are meant to describe. How does one, for example, describe an electron? What is done instead is to represent the object with a suitable visual model. The model may be something totally different than the object being described, but it has a type of allegorical significance, such as using planets orbiting the sun to represent electrons orbiting the nucleus. Both exemplify a manifestation of forces.

The animater has at his or her disposal the computer as the visual modeling tool, plus analogies and models as the sub-structural carriers of meaning. Combining these elements together with the added effect of voice over narration and dramatic orchestration not only develops an extremely impressive demonstration, but facilitates the development of a deeper comprehension of the subject matter.

Using Computer Animation in Education

> Computer animation offers the possibility of providing an intellectual framework for understanding the relative magnitudes of time and of space. For every process, whether large or small, fast or slow, there will be an appropriate scale at which to view it, so that its salient features are clear. The chief task in understanding something is often to inter-relate these scales, and computer imaging may provide a novel way of facilitating this understanding. (Clark, 1981, p.131)

In his book, Thinking Visually, Robert Mckim explores the notion of thinking and seeing functioning together and becoming externalized thinking.

> Consider the sculptor who thinks in clay, the chemist who thinks by manipulating three-dimensional molecular models, or the designer who thinks by assembling and rearranging cardboard mockups. All are thinking by seeing, touching, and moving materials, by externalizing their mental processes in physical objects. Many contemporary thinkers, in science and engineering as well as art and design, respect the fertility of this venerable form of visual thought. (1980, p.44)

It is just this type of external thinking that makes computer animation a natural tool for the visionary thinker. McKim anticipated the value of the computer as a tool for external thought back in 1980.

> The graphic computer is rapidly becoming an extremely important tool for visual thinking. An interactive graphic computer allows visual thinkers to manipulate graphic imagery in space and time, to have access to a vast visual computer memory, to decrease their involvement (by means of the computer's memory function) in routine visualization task, and most important, to handle more complexity faster. When a system for visual group-think is devised, it will very likely incorporate a graphic computer system that will permit colleagues to interact, even though they may be separated by thousands of miles. At this writing, the exciting potential of the graphic computer has not been fully realized. But what is in hypothetical or experimental form now will be in prevalent use in the near future. (p.32-3)

Mckim's prediction was indeed well derived. Students enrolled in Biochemistry and Cell Biology at the Open University in the United Kingdom viewed a unique animation of the enzyme Lysozyme. The production was a joint effort between the Open University and the Laboratory of Molecular Biophysics at Oxford, and the IBM UK Scientific Centre at Winchester. This animation, derived from calculations of the steric and electronic forces on the atoms in the molecule, presented the first view of high-frequency oscillations of the molecule in motion (Ball, 1986).

In another production created to visualize the "Potential-Energy Surface," students are able to see the three dimensional potential-energy surface of the interaction between fluorine and hydrogen. This production entitled "How Do Molecules React?" is for a physical chemistry course which animates a reaction between a fluorine atom and two hydrogen atoms expressed by the equation F+H2 -> FH+H. The animated sequence is derived from an expanded equation put forth by John Murrell of the University of Sussex (Ball, 1986).

$$V_{abc} = V_a^{(1)} + V_b^{(1)} + V_c^{(1)} + V_{ab}^{(2)}(R_1) + V_{bc}^{(2)}(R_2) + V_{ca}^{(2)}(R_3) + V_{abc}^{(3)}(R_1\ R_2\ R_3)$$

(Ball, 1986, p.41)

Terms from this equation represent the energies of the three isolated atoms, three of the possible diatomic species, and finally the interaction of all three atoms with one another. There is a graphical subroutine which utilizes this equation over a suitable range of values calculating coordinates for the potential-energy surface, which it then draws on the display screen. A command file programmed to develop the animation takes over, and the observer's "eye" is "flown" around the surface. This video segment is then combined with an explanatory presentation, which as a total presentation makes it easier for students to understand the thermodynamics of the reaction (Ball, 1986).

In another television production called "Flying in Birds - An Experimental Approach," animation is used to illustrate bird flight.

From studies of many high speed films, Jeremy Rayner of the University of Bristol developed a simple algorithm to describe the movement of the wings of various types of birds in flight as well as the wake associated with this movement (Ball, 1986).

Putting it all together in The Mechanical Universe

Probably no other production exemplifies the potential of computer animated presentation to date better than the television based physics course called The Mechanical Universe. The Mechanical Universe and Beyond the Mechanical Universe represent the first and second semester courses each consisting of 26 half-hour television lessons. These programs contain very sophisticated computer animation which is used as the primary tool for instruction in physics. Opening and closing remarks of each program are provided by Caltech Professor David Goodstein, who provides philosophical, historical and often humorous insight into the subjects. In addition to the computer animation the main content of the lesson is presented through original location footage, physics experiments or demonstrations, and historical re-creations, all tied together with voice over narration (The Mechanical Universe, 1985).

All the major components of scientific learning discussed so far concerning visualization, models, and analogies and their relationship to problem-solving, are artfully combined in this presentation to launch the viewer into a level of comprehension of physics previously thought incomprehensible.

One of the greatest accomplishments achieved in The Mechanical Universe series is its unique method of presenting mathematical material. Through the use of computer animation, mathematical relationships are numerically expressed on the screen side by side with their corresponding pictorial counterpart. When motion is depicted in the pictorial section of the screen, the numerical formula moves as well to reflect how the mathematical representations change in accordance to the pictorial. This technique known as Algebraic Ballets have earned The Mechanical Universe a great deal of acclaim amongst non-science undergraduates as well as educators. Actual comments reported from educators and students have been "...These are simply some of the best science audio-visual materials I've seen." "This is the best material I have used for teaching physics." Students commented that it 'wasn't boring' and that it helped them to understand and 'see in ways we normally can't.' (Adapting TMU,1985, p.10)

David L. Goodstein, narrator for The Mechanical Universe, had this to say about the role computer generated animation made:

> For all the excellence of the series, Jim Blinn's computer animation is undoubtedly the jewel in the crown. Vivid and brilliant images allow the viewer to see the evolution of a galaxy or the vibrations of atoms in a crystal, or even the fabric of space-time in the theory of relativity. Algebraic manipulations become an entrancing dance of animated characters, endowed with drama and humor. Above all, ideas that are next to impossible become indelible images impressed forever on the viewer's imagination. (O'Neill, 1986, p.35)

CHAPTER IV

Conclusion

Summary

The underlying theme of this paper is that imagery lies at the core of understanding complex technical processes. People of vision have struggled throughout history, with varying degrees of success, to transmit their understanding of complex technical processes to others. In their attempts to communicate, two prominent modes, linguistic and pictorial, have been utilized alternately depending on the relevancy the mode of communication has on the message to be communicated. Historically, the pictorial mode has run a close second to the linguistic due to the relative ease and cost of the printed page as opposed to the printed image. Reliance on the linguistic mode of communication, however, has one significant drawback. How can one be sure that the concept of reality expressed by the author is the same as the concept of reality received by the reader? If the content of the thought is pictorial in nature, is it not the case that a pictorial mode of communication has a superior chance of reliably transmitting that concept than a linguistic? With the case of computer generated animation, both pictorial and linguistic modes of communication are used via textual information added to the visual presentation as well as voice over narration.

Even more important is the need to pictorially depict phenomena in the universe which cannot be seen with the naked eye such as electricity and magnetism. It is one thing for someone in New Jersey to describe a Pontiac Fiero over the phone to someone in California who only needs to take a look out the window to identify a car that matches such a description. But imagine how complicated it is to reveal information about elements in our universe that cannot be viewed by anyone. Evidence has been provided through the literature to support the notion that this is the complex level of communication in which computer animation can be most effective.

This author had the opportunity to visit with a small group of college juniors and seniors who had just seen a portion of Beyond The Mechanical Universe concerning the theory of relativity. All of these students had had physics and had studied the theory of relativity before from traditional textbook/lecture formated classroom presentations. But now for the first time everyone in this discussion was able to discuss this topic with a deeper sense of certainty than they could before seeing the animated presentation. The visual presentation had so vividly reinforced their intuitional understanding of the theory of relativity, as well as dissolving their inhibitions rooted in their belief that it is too complex or difficult to comprehend, that they were now able to discuss the theory of relativity confidently amongst themselves, and describe it confidently to others who had not seen the presentation.

This sense of certainty described above about the way students responded to the material presented in the computer animated format is more often the rule than the exception, based on personal observations. It has also been noted that no matter what level the student is in regarding the understanding of physics, there has always been some benefit derived from viewing The Mechanical Universe even if it was only that a familiar concept was viewed in a new and more meaningful way.

Recommendations for Further Research

Further research is possible in the area of utilizing computer generated animation in instructional presentations. A standard study comparing a traditional textbook/lecture presentation with a computer animated presentation would be suitable. Such a study, however, will require careful attention to the evaluation process to avoid bias. Those who received a pictorial presentation may not get the same queues from a written objective evaluation as those receiving the textbook/lecture presentation. Those receiving the pictorial presentation might be most fairly evaluated with an essay type test where they are asked to describe the process covered in the presentation. This may not be appropriate, however, for the textbook/lecture group who would probably respond better to an objective evaluation.

Another study might be a survey to determine what students in different fields of study would most appreciate to see presented in the computer animated format. This study would require informing those in the survey just what is possible with computer animation so respondents will know what is realistic to ask for as well as how complex the imaging problem can be.

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