Strategic training in the use of causal diagrams: Facilitation of superior mental models

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STRATEGIC TRAINING IN THE USE OF CAUSAL DIAGRAMS: FACILITATION
OF SUPERIOR MENTAL MODELS

by

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Bachelor of Arts
University of California, Santa Barbara
1978

A thesis submitted in partial fulfillment
of the requirements for the

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ABSTRACT

Strategic Training in the Use of Causal Diagrams: Facilitation of Superior Mental Models

by

Anne Seyer Poliquin

Dr. Gregg Schraw, Advisory Committee Chair
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This study focused on the influence of strategic learning on the construction of causal diagrams and their role in text learning. A causal diagram is an instructional adjunct designed to enhance text comprehension by providing a visual representation integrating elements of cause and effect. The Integrated Model of Text and Picture Comprehension (IMTPC) (Schnetz & Bannert, 1999) suggests that diagrams improve learning because they facilitate the construction of mental models via simultaneous comprehension of visual and text elements. However, there is no information on how to achieve this benefit consistently. Scevak, Moore, and Kirby (1993) have demonstrated that this benefit is enhanced by strategic training. The present research examined the effects of strategic training on causal diagrams to improve text learning. It was predicted that individuals who received training would perform better on measures of factual and conceptual learning than those with no training. These results supported the IMTPC model.
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CHAPTER ONE

STATEMENT OF PROBLEM

This study examines the role of causal diagrams as an adjunct to text in an instructional setting. The term ‘causal diagram’ refers to a graphic designed to show the chain of cause and effect between two or more variables (see Figure 1). Causal diagrams are a type of graphic used as an adjunct aid to comprehension commonly found in the field of statistics and social sciences. Learning is improved by the effective use of graphical displays (Shah & Hoeffner, 2002; Griffin & Robinson, 2000; Verdi & Kulhavy, 2002; Verdi, Stamm, Johnson, & Jamison, 2001; Shah, Mayer, & Hegarty, 1999). However, research has indicated that students can misinterpret information presented in graphics (Shah, 2003; Shah & Shellhammer, 1990). Therefore it is critical to determine whether valuable instructional time would benefit students’ ability to effectively utilize graphic displays such as causal diagrams during reading.

The Integrated Model of Text and Picture Comprehension (IMTPC) (Schnotz & Bannert, 1999) provides a theoretical explanation for how diagrams can be helpful during learning. For example, diagrams improve learning because they facilitate the construction of superior mental models via simultaneous comprehension of visual and text elements (Baddeley, 1992; Chandler and Sweller, 1991). The construction of mental models is facilitated through the use of compatible cognitive resources for visual and text-based
information. Thus by facilitating the production of a superior mental model (leading to deeper comprehension), text comprehension should be improved. This process positively impacts working memory by maximizing resources when the text and graphics are both effectively being utilized. However since graphic adjuncts do not always improve comprehension (Scevak, Moore, & Kirby, 1993), strategic training may provide a means to facilitate their use.

Pearl (2000, p. 97) states that causal diagrams arose from the need to provide “an alternate language for combining data with causal information.” Text is embedded within a type of flow chart and the spatial relationship between elements indicates relationships and their sequence in time. A causal diagram is a simple graphic way to show a complicated chain of events.

Causal diagrams depict two main types of effects, direct and indirect. A direct effect occurs when a change in one variable causes a direct change on a second variable. An indirect effect occurs when a change in one variable causes a change in a second variable, which in turn, causes a change in a third variable. Causal diagrams are often paired with correlational data to indicate the strength or weakness of the variables involved.

Previous research indicates that reading a text that explains causal relationships is enhanced with a pictorial representation of causal relationships. Schraw, McCrudden and Poliquin (2003) compared a group that viewed a causal diagram while reading to a control group that did not receive a causal diagram. The current research extends this work by investigating the effects of training with the causal diagram. Training should improve learning because the purpose of the causal diagram was explained and the
participants were shown how to read the diagram. In addition the participants were introduced to the concept of direct and indirect variables. Therefore the participants should understand how to use the diagram and its relationship to the expository text. Figure 1 shows the causal diagram model of current science achievement used in this study.

In this experiment I examine whether learners achieve greater comprehension and recall when they receive strategic training in the use of causal diagrams and how they are intended to help the learner. Training was included to determine whether causal diagrams could be more effectively utilized after instruction. Of particular interest was whether training would increase learners' retention of expository text. In the present study one group received training to improve their understanding of causal diagrams and another group did not. Both groups then read a 1,700 word text on science achievement and drew a diagram of the relationships described in the text.

Purpose of Research

The purpose of this research was to determine whether training with a causal diagram would enable students to better understand a text that describes causal relationships. Strategic training in the construction of causal diagrams should lead to active learning and improved comprehension. The participants should be able to more easily create an integrated model of the text and the relationships among the many variables. In short it would be easier to remember. I predicted that a brief instruction period would produce superior drawings of the relationships between the variables in the text, greater recall and better comprehension. This process was examined theoretically.
using a method that examines the role and interaction of mental models developed from text and picture comprehension.

The IMTPC Model

This research is based on the Integrated Model of Text and Picture Comprehension, (Schnotz and Bannert, 1999). This model provides one way to examine the integration of text and pictures during text processing. Recent research in text and picture comprehension includes the assumption that the reader creates his or her own mental model at both a surface and propositional text level (Graesser, Millis, & Zwaan, 1997). A surface text base is not as deep an interpretation as a propositional text base which is more elaborate since it requires intellectual decisions like belief, doubt, denial or acceptance. Distinguishing between these two levels is important because individuals can learn at a shallow level without deeper understanding.

In the IMTPC model (see Figure 2), the readers' information is developed in stages, first on the surface and then at a more sophisticated level. Thus, the information from a text that a reader inputs first is processed as a surface representation. This involves a form of early semantic processing. This function is almost like the production of a cognitive summary, a precursor to what the text is about. It helps the reader determine where the later semantic processing is going to need to highlight salient related information to strengthen the summary. When the text is next processed semantically a deeper type of learning occurs which leads to propositional representation. In order to reach the conceptual organization necessary for a mental model, the text has to be filtered
through this semantic pathway. In other words, deep meaning requires stages of interpretation and the integration of new and existing knowledge.

One branch of the IMTPC model depicts the processing of descriptive or text-based information, while the other is concerned with depictive or imaginal information (see Figure 2). Both branches work together to produce integrated mental representation. The IMTPC and other theories such as Dual Coding, Conjoint Retention and Visual Argument are attempts to explain why pictures and text work together in assisting individuals with cognitive recall. They are briefly described in Chapter Two. IMTPC has its roots in dual coding but it is a solution to working memory issues that does not rely on two independent channels. Rather, it described two specialized pathways.

Predictions

This study compared two groups, one that received training in how to understand causal diagrams, and one that did not. All students read a text on improving science achievement and attempted to draw the causal relationships described in the text as they read. The *training hypothesis* states that training prior to reading enables students to better understand and draw causal relationships described in the text. The *non training hypothesis* states that training has no effect. I predicted that the training group would be better able to understand the text at an explicit level. The training would also enable the learner to create an integrated mental model of the new information. This mental model would facilitate deeper understanding and provide a larger effect size in the recall and comprehension measures among the training group.
I predicted that the training group would produce clearer drawings, and would recall more important propositions. I expected to find that the no training group produced more erratic drawings and less recall of important propositions. I expected the no training group to produce drawings with greater numbers of facts but be unable to produce a cohesive diagram or pathway between the variables that they learned about in their text. My expectations were that instruction would play a role in improved recall of variables for learners in the training group. I predicted producing a visual diagram when the material is presented would enhance this effect.
CHAPTER TWO

LITERATURE REVIEW

Research into the role of graphical displays is growing. In this ever changing technological world it is more common to see graphical displays (henceforth graphics) than not. There are many questions as to how graphics work best to facilitate learning.

Causal diagrams have not been well researched. Causal diagrams are visual displays that show the direct and indirect relationships among multiple variables. However in the interest of providing a background about their significance, I have included some research into the role and history of graphics in the hard sciences and soft sciences. Research about cognitive interaction with graphics is usually found under the theories of dual coding, visual argument, and conjoint retention. In particular dual coding is one of the best-known theories used to explain the power of pictures as memory agents. I will review these theories briefly later on.

This chapter is divided into seven sections. Section one describes the importance of graphic displays and their role in scientific education and printing. Section two presents an overview of research on the effectiveness of displays. Section three provides a comparison of the theoretical explanations for the effectiveness of displays; dual coding, conjoint retention, visual argument and the Integrated Model of Text and Picture Comprehension (henceforth IMTPC). Section four details the significance of strategic training in the use of graphics, but especially the research findings of Scevak, Moore and
Kirby (1993). Strategic training using graphs is an important variable in my study. Section five summarizes some general design principles that effective displays utilize. Section six describes the goal of this study. Finally, section seven concludes the chapter with a summary of my hypotheses and predictions for the research.

**Importance of Graphical Displays in the Sciences**

The work of Smith, Best, Stubbs, Archibald & Roberson-Nay (2002) details the importance of graphics and tables in social sciences, or as they call them "soft sciences." Two quotes illustrate the differences of opinion about graphs and tables:

"Facts" are visually supported beliefs shared by the community and visual demonstrations introduced in a persuasive process (Campbell, 1996, p. 121),

and,

Visual displays are distinctively involved in scientific communication and in the very "construction" of scientific facts (Lynch, 1990, p. 153).

The title of this article is curious and indicative of the some of the dichotomies that exist in the scientific world. It is “Constructing Knowledge: The role of graphs and tables in hard and soft psychology”. This article illustrates some of the questions that exist about the role of graphics in science and concerns about their effectiveness in illustrating concepts correctly.

In the process of seeking to understand science there are representational techniques. Latour and Woolgar (1986) refer to these as "inscription devices" (p. 51). These devices are graphs, tables, diagrams, and other types of graphical elements
considered to be an alternate language (Pearl, 2002). Smith et al., consider some of this
graphic use to be a product of the battle to convince others about the worthiness or
significance of one’s work. Graphics often have a role above and beyond the actual
reason for their inclusion. They serve as a persuasive process for research issues and
agendas that cannot often be addressed through text.

Latour (1990) points out that most scientists never see their subject matter and
what they see instead is an inscription, which seems to be a natural phenomenon
(Golinski, 1998; Lynch & Woolgar, 1990; Woolgar, 1988). Inscriptions are the facts not
the impressions of science. Therefore they are more long lasting and identifiable.

The value of inscriptions is not denied (Lynch, 1990; De Mey, 1992). Golinski
refers to inscriptions as "ocular proof" in their powerful role as observational elements.
Inscriptions cover a wide range. Not all are valuable. A growing trend among
ethnographers and historians of science is the consideration of graphs as a "potent and
persuasive type of visual device" (p. 751).

Scientists consider graphs to be powerful. Latour (1990) delineated these features
as, readability, scalability and their ability to be combined. They are also immutable,
mobile and persuasive. Readability is an obvious yet hard to rely upon feature. Graphs
allow the presentation of data is such a way to make the results viewable from anywhere.
This is what Shapin and Schaffer (1985, p. 60) call "virtual witnessing." Complex data
can be comprehended through the medium of this type of visual aid, and it is enhanced by
the human capacity to recognize patterns within visual information.

Scalability refers to the important feature of instant enlargement for the public,
the domain peers and others attempting to study the data. The combinability of graphs
concerns the potentially fascinating relationships that can occur from the imposition and superimposition of data that may lead to unimagined relationships.

Graphs also have the quality of immutability. This is harder to define but refers to the unchanging aspect of the informational context once the learner assimilates the graph. Before this point there is a static point of reference that all scientists can refer to. Immutability refers to the fact that the information presented in graphics is fixed to the actual presentation, and is not subject to change. There is less room for misinterpretation once the graphic is correctly processed. For instance a bar graph that shows population growth across the years will portray the same information today as it will when someone looks at it in the future. An immutable graphic is static; there is less chance of misinterpretation due to poor descriptive language.

Mobility concerns the ability of the graphs to be produced in different applications without great levels of transformation. For instance once the data is available then it is simple to produce a number of graphs in most word processing programs. One can convert from a mainstream statistics or scientific application and back to a word processing application and reproduce your graphic simply and change its appearance as well. Graphs can be reduced or enlarged, one can add color or take it away.

Persuasiveness is the power of graphs to persuade, convince, allow doubt, dissuade or generally produce an atmosphere of conviction or disbelief. This quality of persuasion is extremely important in the scientific field because the data represented allows one to either present new information or agree with the interpretation presented. Latour (1990) calls this phenomenon a type of event where "inscriptions allow conscription" (p. 50).
Latour (1990) says that scientists are particularly susceptible to the power of
graphism (p.39). So it is particularly relevant to say that graphs and other sorts of visual
aids have been a significant factor in the increase of science understanding. Graphs are
relatively easy to produce, which is part of the problem, since graphs may be created by
formula not by design or purpose.

Smith et al. (2002) consider tables and graphs to be the most frequently used
inscription device employed in the dissemination of science. Therefore they are very
influential. There is some debate about the helpfulness of graphs, some scientists consider
them to be “perceptually inefficient, rhetorically unconvincing, and often perfectly
undecipherable” (p. 753). However, on the other hand, tables are thought to be easily
assessed for precise numerical values. It is curious that scientists find the apparently
straightforward presentation of tables to be misleading and often inaccurate (Bastide,
1990; Krohn, 1991). In other words this means that the design and presentation of
material determines its worthiness.

The work of Shah and Hoeffner (2002) indicates that there may be a degree of
misinterpretation in the reading of graphs or lack of graphical knowledge. Graphical
literacy skills are necessary and should be taught in the context of science and social
science. Errors in graph comprehension may occur if there is inconsistent or inadequate
prior knowledge (Shah, 1995). Shah and Shellhammer (1999) found that less skilled
graph users had more difficulty in identifying trends than did more skilled users. In Table
1, I have presented some research into the use of graphics, in particular the effectiveness
of instructional materials, such as diagrams.
The shift to using graphs has been gradual. To quote a significant comment by Doherty, Tweney & Mynatt (1981) "we know from several lines of research that people are good at detecting weak signals in perceptual links, but not very good at making comparable judgments about numerical data" (p. 263).

Tables alone may not provide enough inferential information therefore they are suspect. However, effective graphs have enough reference points to enable scientists to make accurate assumptions about the material within. A question arises however, if scientists have trouble interpreting some of these graphical elements, how can students be expected to understand them and utilize them effectively in an instructional situation?

An important point is raised by Smith et al. (2002) is that graphs may serve to illuminate the rethinking of dependent variables in research. The powerful use of graphs is not restricted to students but includes educated professionals. Tukey (1977) says, "graphs can reveal the unexpected" (p. 759).

Graphics are clearly important in communicating both the simple and the complex. Science relies on graphs more and more for their persuasive power and their ability to succinctly display data and associated relationships. Graphics can illustrate extremely complex concepts with greater ease than prose. They provide representational techniques to clearly display relationships among data. Graphics are mobile and immutable. However research has shown that the development of graphics comprehension requires training, and the misinterpretation of graphics is common (Shah, 1995; Shah & Shellhammer, 1999).
Research on the Effectiveness of Graphic Displays

Research in causal diagrams is limited. Research on the use of other graphics such as maps, is more prevalent, but there are commonalities among all graphical displays. Successful use of causal diagrams in text instruction may involve several variables. Individual differences, lack of previous instruction and inadequate instruction may play a role in the use of graphs or more specifically causal diagrams (Shah, 1995; Shah & Shellhammer, 1999; Shah & Hoeffner, 2002; Carney & Levin, 2002). There are a number of variables that may directly relate to the adjunct's effectiveness. These variables are prior instruction, appropriateness of use, and design considerations dealing with legibility and clarity. In addition the integration of text and visual information may require alternate forms of cognitive processing (see Table 1).

Quantitative and scientific concepts are sometimes more easily understood through graphs or visual displays (MacDonald-Ross, 1977; Tversky, 2003; Winn, 1987). However as Shah and Hoeffner (2002) point out, some graphs are easy to comprehend for one purpose and may be harder to interpret for other applications without specific instruction (see Table 1). There are questions about the role of prior knowledge in comprehension and individual learner characteristics. Shah and Hoeffner describe factors that affect the use of graphs, they include knowledge of the conventions and properties of the graph itself as well as the existing knowledge base. The interpretation of the graphs may be tied to the ability to create or correctly read a graph. Shah and Hoeffner refer to this ability to comprehend graphs as a form of “science or social science reasoning” (2002, p. 65).
The term graphical aids, covers a wide spectrum of items including visual displays, graphics and graphical representations. Vekiri (2002) defines these types of adjuncts as “displays that represent objects, concepts, and their relations using symbols and their spatial arrangement” (p. 262). Furthermore Bertin (1983) describes graphics as unique and unambiguous. The properties of any graphic are determined by previously established conditions or standards. Causal diagrams would fall into this category; they are designed with a specific spatial relationship among elements and include text features with a predetermined function.

The opposite of the role of graphics is that played by pictorial representations. These are cognitively interpreted with ambiguity and subjectivity. For example a painting, photograph or a drawing would be in this category. Learners approach the two systems differently. Graphics direct the learner to or with a specific instructional objective. The relationship that pictorial representations have with cognitive processes seems to be more complicated than those of graphics (Gerber, Boulton-Lewis & Bruce, 1995; Mokros & Tinker, 1987). Since a true graphical adjunct has a specific purpose and derives its identity from its relationship with the text, the learner does not have to deal with subtleties, only the comprehension of the diagrams purpose and message.

Pictorial representations are ambiguous and subjective; therefore their role in science is limited. Graphics are purposeful and much more appropriate for scientific displays. The elements used in graphics have specific spatial properties. Graphics are not random or driven by purely decorative rationale. The ability to read a graph is a form of scientific experience that allows the interpretation of data without an accompanying text.
Types of Adjunct Aids

Among the graphic systems are elements such as diagrams, charts, maps and graphs. These are all commonly used; some it might be said are used of without design considerations but merely as a byproduct of computational ease. Each of these terms has some variation to it. Some researchers call diagrams charts and vice versa (Hegarty, Carpenter, & Just, 1991; Winn, 1987). Some diagrams include matrices and these may also be called knowledge maps. In addition to this the computational ease of graphical production has also led to a blending of graphical formats so they may retain elements of both text and iconic symbols (Atkinson, Levin, Kiewra, Meyers, Kim, Atkinson, Renandya, & Hwang 1999).

Charts are sometimes called knowledge or semantic maps. For instance a chart may be known as an advance organizer when it is used as such. Clearly maps (Lamboitte, Dansereau, Cross, & Reynolds 1989). The use of a chart may also give it a novel the role of a graphical aid changes its identity. Lohse, Walker, Biolksi, & Rueter (1991) created a categorization of displays using research on the naming of graphics by their use.

Maps are an interesting category because they sometimes appear to have no effect and serve only as a pictorial representation in a decorative purpose only (Schraw & Lehman, 2002). Yet when maps are “encoded as intact units, they preserve their visuo-spatial properties” (Vekiri, 2002, p.292). Based on the work of Larkin and Simon (1987), maps are able to promote mental maps that do not exceed working memory capacities, making them a very valuable addition to instructional design. But this does not always happen. If there is a redundancy of verbal information or limited structural information within the map (Kulhavy, Woodard, Haygood, & Webb, 1993c), the learner may not be

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able to correctly use the map. So if students do not remember the structural data, the map loses its positive effect on cognitive load, or what Kulhavy, Stock, Woodard & Haygood (1993b) refer to as the holistic unit retrieval availability. In other words, the map then needlessly adds to the students' workload. The construction of each type of graphics is done with a preconceived purpose.

All of these graphics use slightly different methods of communicating. Schematic pictures are used in diagrams along with objects. Text in a chart generally is framed in a box or circle. This framing may have more to do with separating the text from other elements or to serve as a marker for visual integrity. Within each category of display there are differences in detail. For instance a technical diagram might be very realistic if it was for the purpose of labeling the parts of a starfish, or it might be an illustrative representation of a physical process. The detailed diagram would be considered iconic and the illustrative diagram would be considered schematic (i.e., the nitrogen cycle; Hegarty et al., 1991). The approach used in any diagram has to be appropriate for the intended use of the diagram. This key property for graphic success harkens back to the need to reduce cognitive load constraints imposed by either difficult subject matter or poorly designed instructional materials.

Advantages to Using Pictures as Text Adjuncts

Carney and Levin (2002) found advantages to using pictures as text adjuncts. The properties that enhance this ability are called Levin's five functions (1981). Four of these functions are conventional ones, frequently seen in print material. They are described as conventional, decorative, representational, and organizational. These functions are
common and are driven more by satisfactory visual presentation and by prior learner knowledge. Furthermore these categories distinguish between the normal role of graphical tables and traditional pictorial elements. The fifth convention is transformational; it is an uncommon category that utilizes a specific design and/or intentional placement of text and graphical elements.

There is an association between the similarity of the text information and the representational referents of the picture. An example would be an illustration of a scene in a book. Organization is another type of conventional function. This includes pictorial elements like organizational charts and simple graphs and charts. There is no real inference or interpretation of material in a simple graph. The unconventional or "unusual" function of a pictorial text adjunct is what Levin calls transformational. The picture or diagram provides a link or impetus, to transform the relationship between text and picture, or again what Pearl (2000) calls an alternate language.

The transformational function of text adjuncts is when pictures not only complement text, but also help with memory and recall. These mnemonic effects are very important and cannot be achieved by "pictures" in some of the other functional categories. I think that this is a much harder category to achieve and it requires more thoughtful and deliberate design, as well as text placement. This is an interpretative category.

Causal diagrams would appear initially to fall into one or more of Levin's categories. In order to be effective a causal diagram has to be transformational or interpretational. It is designed with directional and spatial considerations that are driven from the attempt to indicate causality and its relationship to certain variables. According
to Pearl (2000), "the role of graphs is to provide a convenient means of expressing substantive assumptions... these graphs should facilitate efficient inferences from observations" (p. 13). The role of the causal diagram is to provide a road map of variables and their intersections, in order to enable one to interpret a complex relationship.

Carney and Levin produced a list of ten commandments for the judicious use of pictures with text. Pictures (and I use this term broadly to include graphs, illustrations etc.) should be used appropriately, judiciously, must be of good quality and not used with exemplary prose. This may seem like common sense but it is useful to recognize the pragmatism of these properties. Carney and Levin mention that oftentimes, pictorial elements fill up journal pages when they are unnecessary and inappropriate. Recent research on pictures has been focused on provided text, not on the mental models of learners.

Transformational pictures must go beyond the information given (Bruner, 1966) and assist in higher order tasks (Levin, 1986). A causal diagram is definitely transformational. Research needs to clarify many questions about graphical aids but it seems clear that they reduce working memory loads and seem to enhance learning in most circumstances.

Pictorial displays provide an image for those who are uncertain as to the information. They can give a direction for the mental imagery, which can be faulty. This is why pictorial images are not as appropriate in the sciences. The nature of pictorial imagery is not exact and the sciences demand more precision than images provide. Therefore a scientific diagram although it is of a pictorial nature is essentially a graphic. A diagram like this is composed for a reason and detailed with specific variables and
measurements. Pictorial representations best serve theories or simulations are difficult to describe solely through prose. These complex relationships may be difficult to describe accurately using prose alone.

Theories about the Effectiveness of Graphics in the Processing of Text and Pictures

Table 2 provides a brief introduction of the three major theories that I am comparing to the IMTPC. They were predecessors of the IMTPC and provide a history of the attempt to explain why pictures help people remember more easily than just text in some situations. In Table 3 I elaborate on three theories that use dual coding as a base for their assumptions. Dual coding (Paivio, 1990) is frequently cited as a theoretical framework for the reasoning that graphics facilitate learning. According to this theory there are two distinct and independent separate systems involved in the processing of imagery (visual) and verbal (linguistic) information. These two systems are functionally distinct but share some modality-induced (for example auditory or tactile) information. The visual or verbal information is individually processed and stored as modality specific representation units.

Dual coding allows for two pathways into long-term memory. Verbal information (logogens) and images (imagens) are despite their separateness, interconnected in this theory. They do not lose all of the stimuli connected with them and are able to cross associate between systems. For example a spoken word might trigger a mental model or a word read silently might be associated with a remembered object.
Kosslyn (1981) hypothesized that the mental imagery that we cognitively produce is created through visual representation units that are a part of long term memory. The construction of mental imagery has been the focus of psychological studies, and has been shown to support Kosslyn’s hypothesis. Research has shown that the cognitive processes for physical and mental images are similar (Finke & Shepard, 1986; Reisberg & Heuer 2003). For example we can manipulate mental images by making them bigger or smaller, distorting them or rotating them just like we would real pictures. Kosslyn has shown that the bigger or more complex an image is the longer it takes to process.

Flaws in the Dual Coding Hypothesis and Alternative Theories

Johnson-Laird (1998) and Pylyshyn (1973, 1981) challenged the dual coding hypothesis. They claimed that the deeper levels of processing are the result of a single, a-modal form of knowledge representations called a proposition. A proposition is a single linguistic unit (Anderson, 1995). Current research on working memory supports that there are two cognitive systems, which are functionally distinct. There is also some consensus among researchers that there is a non-unitary view of working memory (Miyake & Shah, 1999). These researchers theorize that there are domain specific, individual subsystems for working with visuo-spatial and verbal information (Miyake & Shah, 1999).

One of the more well known of these models was developed by Baddeley et al. (Baddeley & Logie, 1999; Logie, 1995). One system is designated for temporary storage and processing of verbal or auditory information. This is the “phonological loop.” The other system has a similar role in the processing of visual materials (the visuo-spatial
The two sub systems are under the direction of the “central executive” which regulates all of the function of working memory. Baddeley and others (Baddeley 1992, Kruley et al., 1994; Sima & Hegarty, 1997) consider a visual sketchpad to be where the visual perception occurs; it is the imagery portion of working memory (Schnotz, 2002, p. 110).

So there are differing theories about the division of labor in working memory. Dual coding provides for two separate systems while Baddeley and others opt for a division of labor. Baddeley (1992) found that the mental model and the propositional representation continuously interact elaborating new information and adjusting the mental representation as necessary.

Research that supports non-unitary models comes from studies of how individuals react to cognitive load demands for similar concurrent spatial tasks. In other words there is a struggle for resources if the tasks use the same area of processing. This demand is reduced when verbal and spatial tasks occur concurrently (Baddeley & Logie, 1999; Robinson & Molina, 2002; Shah & Miyake, 1996).

Recent studies on brain activity and physiology have shown that different parts of the brain react to the manipulation of visual, spatial and verbal information (D'Eposito, Detre, Aguirre, Stallcup, Alsop, Tippet & Farah, 1997; Jonides & Smith, 1997). D'Eposito et al., also found that the processes of perception and imagery seem to originate and work in the same region of the brain. The suggestion from these psychological and neurological studies is that the commonalities observed in the brain’s manipulation of real and mental models suggests that mental images are composed from visual representations. Propositionalists on the other hand feel that visual information
may be stored in visual and verbal representations as propositions. For example they suggest that the congenitally blind can use imagery, which could not have been formed from visual representations (Reisberg & Heuer, 2003).

Although the dual coding theory is flawed there are substantive elements that may be empirically plausible. There could be two or more functionally distinct means to process verbal and visuo-spatial information. Long-term memory may have both visual and linguistic forms of representations. Visual displays may be an aide to learning because they allow the learner to use two modalities to store the information.

Conjoint Retention Hypothesis

Kulhavy, Stock and Kealy (1993a) and Kulhavy, Stock and Caterino (1994) researched questions about how geographic maps aid in the acquisition of information from an earlier studied text. Conjoint retention is the result, an interpretation of dual coding theory applied to learning from maps. It is compatible with visual argument theory as well. Dual coding as previously stated relies on the existence and integration of two separate systems for storing and representing verbal (linguistic) and visual (imagery) information. In addition conjoint retention relies on the assumption that maps are more helpful in learning than text alone because they can provide spatial and structural information simultaneously (Kulhavy et al., 1993a) and the computational power that they confer on working memory (Larkin & Simon, 1987).

Maps are intact units, accurate about the spatial relationships that exist within text or narration (Kulhavy et al., 1993c). Maps present information in such a way that minimizes processing (Rittschof & Kulhavy, 1998). This is also consistent with visual
argument. It is important to note that conjoint retention depends on the presentation of displays before the text, indicating that the line between optimum learning conditions is important.

The text information inside a map is conjointly encoded and then recalled as a holistic unit in contrast to how text and accompanying maps are encoded separately (Kulhavy, Stock, Peterson, Pridemore, & Klein, 1992). This is an interpretation of the Dual Coding Theory (Paivio, 1986) applied to map learning however it has not been generalized to graphics. The spatial element inherent in a map may be part of the reason that learning may be facilitated (Kulhavy & Stock, 1996; Kulhavy, Woodard, Haygood & Webb, 1993b).

Visual Argument

Similarly to dual coding and conjoint retention, visual argument’s premise is that graphics are more effective as a learning device due to the reduction of demands on working memory. Visual argument theory contends that the Gestalt (Wertheimer, 1938; Winn, 1994) principles come into play during processing, so that graphics are processed all at once and therefore working memory demands are lessened. The visuo-spatial elements are very important in this theory. Spatial characteristics are more salient to learners although they depend on prior knowledge and skills. The Gestalt principles enable one to perceive the whole instead the individual parts. You can imagine looking at a map and seeing it (in your mind’s eye) as a composite image not necessarily seeing only a small section. This ability allows easier recognition of patterns and trends.
However some research has shown that large and complex maps may actually hinder knowledge (Atkinson et al., 1999). This may be due to overwhelming processing demands. But on the other hand tree diagrams were shown to be helpful in drawing inferences about relationships and they required less time to solve problems (Winn, Li, & Schill, 1991). So there are unresolved questions about all three theories, such as the fine line between too much and not enough information. Gestalt principles like connectedness and proximity are evident in all three theories. Research questions generated by inconclusive results from these theories concern the role of learner characteristics, appropriateness of diagram selection, memory issues and the cognitive nature of maps themselves.

The Integrated Model of Text and Picture Comprehension

The Integrated Model of Text and Picture Comprehension (IMTPC) (see Figure2) from Schnotz and Bannert (1999) differs from dual coding because it does not hypothesize an independent and separate cognitive pathway, merely an alternative method of processing information. It is almost as if the mind decides which method to use or language to use in the processing of pictures or text. The brain may be able to allocate resources depending on the perceived needs of working memory. Perhaps the picture processing occurs in a depictive language while the text is processed in a descriptive language. Learning is affected by visual and text displays, they interact and in this model the depictive branch and verbal branch exchange information up and down and left and right. The model describes the mental model creation occurring at the top of the two branches. Semantic relationships have been established and the two types of information have been integrated into a seamless propositional concept.
Integrative processing has to occur for an individual to process or learn both visual and verbal information. This is most likely if verbal and visual information is available in working memory at the same time (Baddeley, 1992; Chandler and Sweller, 1991). Schnotz calls this "the parallel construction of two kinds of mental models that are finally mapped onto each other" (2002, p.108). In order for graphical aides to be effective this simultaneous availability seems to be very important.

In the IMTPC model it is important to note that depictive elements can express specific negations. For instance it is easier for a text message to state simpler messages than for a picture to illustrate, however the more complicated a message, the more a combination of text and picture becomes advisable. Refer back to the IMTPC (see Figure 2) model and the top-down processing that allows for the activation of specific schemata to provide the best fit "to the incoming information" (Schnotz, 2002, p. 109). This organizing function is crucial to a pragmatic and flexible model because the organization that occurs is done on the fly and efficiently, hence allowing for less cognitive effort.

I would argue that the IMTPC is closer to Baddeley's visual sketchpad than the dual coding assumptions. Schnotz's model is similar to dual coding but relies on a belief that verbal and visual information are two differing types of sign systems and that they use different principles of complementary representation. Verdi and Kulhavy (2002) differentiate between the two kinds of information that can be found in graphical displays, feature information and structure information. The "what system" is feature dependent and the "where system" is structure dependent. These two interact to tell the viewer what happened or exists where. Research has shown that these systems are different, knowledge about the location or spatial attributes (Kosslyn, 1991) is different.
from that of identification of objects; brain damaged patients can find objects but can't identify them (Farah, Hammond, Levine, & Calviano, 1988).

The IMTPC is a fairly simple explanation for how we learn when confronted with information embedded within a graphic. I would argue that it is superior to the dual coding theories because it does not depend on two distinct cognitive channels merely a unitary system that uses different input elements (i.e. words or visuals). If you consider the hierarchical arrangement of this model it is clear that the mental model stage relies on deeper comprehension, which has occurred along and within both branches.

Learning is a process that requires complementary and distinct exchanges among the text and visual based information. Sometimes information may not need too much of an exchange, this might be affected by prior knowledge. In this case you might have a mental model created more expeditiously than when the learner has to combine and recombine new and existing references in memory.

Schnotz has relied on the differing sign systems that humans use in describing the processes of this model. If we consider that these sign systems have a very long history in human use then it would make sense that the mind uses different methods to absorb and integrate information effectively.

Strategic Training with Maps

A number of studies have investigated the effect of maps on learning. However, only one study has examined the effect of training to use maps on learning. Scevak, Moore and Kirby (1993) provided training to high school students in the strategic use of adjunct maps included in a history lesson. This study was designed to determine what
benefit if any, students would receive from strategic training in the use of maps as text organizers. Since this was a classroom study the training was integrated into the school history curriculum. This included feedback on the use of the strategy taught to increase the possibility that the students would be able to use it in a transfer task (cf. Palincsar & Brown, 1983) thus showing deeper comprehension.

The participants were thirty-one (16-17 year old) students in grade 11. The training text “Gallipoli” was about the two horrific battles fought by Australian soldiers on the Gallipoli peninsula in Turkey during World War 1. The Gallipoli battles are very important in the history of Australia and are heavily studied during Grade 11. The text was just under 1800 words long and primarily described the reasons for the failure of the campaign. The participants also studied three adjunct maps.

The three maps varied in size and detail of subject matter. The first map illustrated Europe and the Middle East. The second map illustrated only the Middle East. The third map showed the Gallipoli Peninsula itself and had the major geographical features indicated on it.

Both the training and control groups received the accompanying maps and same lengthy training text. The training text group received a copy of the third map, on which they were asked to place as many details as they could. The basic strategies employed in the training were summarizing, linking (the integration of features and events information), imaging and checking. The teacher modeled the placement of important information on the maps by demonstrating for the class via an overhead projector. In contrast, the control subjects read the passage silently while the teacher read the text
The teacher questioned the group about the text and the maps. The control group was then told to write an essay about the reasons for the failures at Gallipoli.

On the next day, the training group had their maps returned to them. They were asked to recall as much as they could from memory about the Gallipoli campaign, using their maps to help them. Participants were encouraged to use mental imagery and to check against what they actually had on their maps. The session finished with the participants placing as much information as they could onto an outline map of the Gallipoli Peninsula. The control group finished their essays on day two.

Students' text recall of the Gallipoli text was analyzed using a text analysis procedure developed by Kirby and Cantwell (1985). The propositions were rated by the degree of map-relatedness. Scevak et al., used three different levels of propositions, high, medium, and low map-relatedness. The maps were scored for the number of features correctly placed on them, the number of features included, the number of events included and the number of events placed accurately.

The training group results showed that when training deliberately integrated features and events on a map there was a significant improvement on all of the measures included text recall and map element recall. These effects were not limited to any particular type of information, or level of importance.

Benefits of Strategic Training

The results of the Scevak et al. study appear to suggest that strategic training in the use of graphics, maps, charts diagrams etc., results in improved comprehension and demonstrated a benefit to including graphic adjuncts with texts. Furthermore, there were
no deleterious effects of the training for any of the outcome measures. This is significant because previous studies have shown that map use might inhibit higher-level recall (e.g., Kirby et al., 1984; Moore, 1988). The IMTPC model illustrates the pathways and methods that provide this increased comprehension and recall for learners. It is especially important to recognize that this improved recall and comprehension does not tax working memory. For example, the learner has simplified and strengthened their mental models and thus can use their resources more efficiently when answering questions.

There are issues about map use that can be generalized to any kind of graphical adjunct. Strategic training appears to resolve or mediate any comprehension issues existing in the participant's schema. Scevak et al. (1993) found a strong correlation between the benefit of the training and the degree to which it was practiced. This contradicts earlier studies that have shown that maps do not enhance the recall of map-related information. The implication is that with strategic training and increased graphical literacy, visual adjuncts can greatly improve comprehension, recall and more importantly deeper processing.

Verdi and Kulhavy (2002) researched the use of geographic maps presented in conjunction with verbal elements. They overviewed the use of spatial aids in particular geographic maps. They had questions about how students use maps. Students use maps as a main organizer, or simply as decoration (Davis & Hunkins, 1968). Tyner (1992) found that maps are more often used as decoration, and they do not aid learning as one might expect. Schnotz and Kulhavy (1994) found that it is the effective design and application of graphics and maps that make a difference in learning. Their proper use may greatly aid instruction.
General Design Principles and Graphical Literacy

Shah and Hoeffner (2002) present a number of suggestions to improve graphical display learning instances. They cite the principles of proper graph design from the work of Kosslyn (1994) and Tufte (1983). There are too many to mention here. Suffice it to say that causal diagrams do have to be designed with these guidelines for maximum effectiveness. In particular, reduce working memory demands, use the format depending on the communication goal and make the information and visual display consistent.

Shah and Hoeffner discuss a very important issue when they consider the idea of graphical literacy especially in the hard and soft sciences. They state that graphical literacy should be taught and is generally not obtained until later in one's academic career. There is an assumption that students “know” how to read graphs or diagrams. Unfortunately they have studies (Shah, 2003) that show that there is often misinterpretation. Less skilled users also had trouble identifying trends or patterns than more skilled users (Shah & Shellhammer, 1990).

In the elementary grades there are frequently misinterpretations in the analysis of graphs with representations of change like growth or speed. Leinhardt, Zaslavsky and Stein (1990) found that this was remediated by teaching basic graphing skills. There is also confusion among novice graph users especially when their content area is low. There is a “graph schema” that affects the use of graphs (Pinker, 1990). This is one of the areas that is important to research concerning causal diagrams because the initial instruction before use or creation may eliminate ambiguity or misconceptions. Assumptions about the readiness of students to interpret graphics efficiently and moreover correctly should be an important criterion in science and social sciences.
The Goal of this Study

The goal of this study was to measure the effect that strategic training had on the learner when using or producing a graphic adjunct. Strategic training has been shown to influence and increase recall in the use of maps and the associated text. Graphics reportedly facilitate some types of comprehension. I predicted that training would lead to higher recall and comprehension. Furthermore I wanted to examine whether the training group would show better overall performance or if they would show improved performance on only certain measures.

The purpose of the present research was to examine the effects of a causal diagram with or without training on different aspects of text comprehension. Research has been done on commonly used graphic organizers like flowcharts and graphs (Shah & Hoeffner, 2002), traditional maps (Griffin & Robinson, 2000; Verdi & Kulhavy, 2002; Verdi, Stamm, Johnson, & Jamison, 2001; Shah, Mayer, & Hegarty, 1999), and instructional animation (Mayer & Moreno, 2002). Generally these studies found that if the graphic organizers are well done and understandable, then learning is facilitated. The key here is understandable, not only the design must be clear but the purpose of the diagram itself. Strategic training may be more important than the design of the graphic organizer since if the learner understands the focus and goal of the diagram it would seem that learning would be richer and more direct.
Hypothesis and Predictions

My hypothesis was that the training group would outperform the non training group in recall by producing more claims derived from the text. Further, I expected that the training group would be more focused than the non training group, and that this would be apparent in the ideas units recalled from the text. I predicted that the training group would rely on the principles described in the instructional sequence, thus scoring higher in the short answer questions.

I also expected that the causal diagrams drawing would be different between the two groups. I expected that the training groups drawings would be simpler and consistent with the tutorial. I predicted that the drawings done by the non training group would demonstrate a range of styles in producing their graphics. I expected that they would be more disorganized and include redundant or unnecessary information.

I further hypothesized that the causal diagram would serve as a graphic organizer to guide the integration of an annotated mental model for the training group. This mental model would provide a detailed and complex pathway that would encode and facilitate the retrieval of information. In the IMTPC model, (see Figure 2) the processing of visual and verbal information is achieved through two distinct pathways that reduce cognitive overload and complement each other to assist in memory intensive processes. The IMTPC allowed the learner to use the information in the unique causal diagram and cross index it with the expository text that was read.

When learning is easier the mental model that is created is better and included more propositions. I expected to see more distinct recall in all of the training groups measures. I did not have a prediction as to the overall amount of information that the no
training group would produce. It might be that the lack of instruction would produce an abundance of information that the training group was trained to eliminate.
CHAPTER THREE

DESIGN

Sixty-two undergraduate students from introductory educational psychology and tests and measurement classes at the University of Nevada, Las Vegas, participated in partial fulfillment of their research requirements for Educational Psychology (EPY 303) and Tests and Measures (EPY 451). Each participant received one credit for an hour of participation. Participants were randomly assigned to one of two conditions. The first students in the condition received brief instructions in how to read and understand a causal diagram. The students in the second condition did not receive any training. The study was run in two sessions of each group.

The instruction group received a brief tutorial about the use of causal diagrams, and examples of direct and indirect effects. The flow of items in a causal chain was illustrated. In addition the role of arrows and the relevance of spatial placement was emphasized. They briefly saw a practice diagram unrelated to the text. The tutorial group saw a simple diagram indicating the steps of the study and the goal for the training.

Both groups were asked to create a causal diagram while they read an expository text on improving science learning. I predicted that the treatment group would produce a more organized and accurate causal diagram due to the brief instruction period. I also predicted that the claims from the treatment groups would be higher and that there will be superior focused recall due to the instruction intervention. The training group had an
additional advantage because they were briefly introduced to the notion of causality and the role of direct and indirect effects in explaining improving science education.

After the tutorial all procedures were the same. Both groups used the same materials to measure immediate factual and conceptual understanding of the text’s main ideas. There was a recall measure. This measure asked participants to recall as much as they could from the story. They were asked to please try to remember as much as possible, even if they have put it into their own words. In addition they were reassured to not worry about spelling and punctuation.

In addition the participants were measured on their holistic interpretation of the text’s key issues in essay form. The essay asked participants to tell us whether they thought the research on improving science education was important. Specifically they were told, “Please state whether it is important or unimportant, and tell us why you thought so. Try to link this research to your own school experiences. In addition, comment on whether you personally support this kind of research (e.g., does it contribute to society as a whole)?”

Both groups responded to four short answer questions that were designed to indicate inferences and deeper processing derived from the text and or prior knowledge. This was the text for the short answer questions. "In this part we want you to answer the short questions below. Please use complete sentences. What is a structural model and how do researchers test it? What is a direct effect? How does it differ from an indirect effect? Give an example from the text for each. Can you think of other variables that were not included in this research that should be? Explain why they are important. What
should assist the learner in identifying the key variables and therefore make it easier to remember and develop an implicit understanding. Secondly I wanted to investigate whether the non-training group would produce similar types of drawings or if they would widely dissimilar. The research on graphical literacy (Shah & Hoeffner, 2002) seems to indicate that there is a wide disparity among students concerning their ability to read graphs and tables. Therefore it would seem logical that the ability of students to produce their own diagrams would also vary.

Independent Variables

A brief instruction sequence was provided for the experimental group that is summarized in Table 4. They were exposed to a brief description of indirect and direct effects with examples of each effect such as smoking causes cancer (a direct effect) and that smoking causes a need for greater respiratory nurses (an indirect effect). Participants were instructed how to interpret a causal diagram, what the arrows signify and the top to bottom or left to right sequence in reading a causal chain of events. Participants were also instructed as to visual cues indicated by the important spatial placement of variables in the diagram. They were given a practice diagram to study (see Appendix J). This diagram was not related to the text. The participants were shown a step-by-step guide to the research that also concluded with the hypothesis for the study that instruction in the use of causal diagrams would result in increased comprehension and deeper levels of meaning (see Table 5).

Two graphic examples were produced to explain the rationale and methodology behind the tutorial (see Table 4 and 5). Instruction improves one’s ability to understand
should assist the learner in identifying the key variables and therefore make it easier to remember and develop an implicit understanding. Secondly I wanted to investigate whether the non-training group would produce similar types of drawings or if they would widely dissimilar. The research on graphical literacy (Shah & Hoeffner, 2002) seems to indicate that there is a wide disparity among students concerning their ability to read graphs and tables. Therefore it would seem logical that the ability of students to produce their own diagrams would also vary.

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Two graphic examples were produced to explain the rationale and methodology behind the tutorial (see Table 4 and 5). Instruction improves one’s ability to understand
slightly longer experiment due to the ten-minute tutorial. Both groups got a warning
during each step of the study when a minute or two was left for each remaining task.

The uncued recall asked the participants to recall as much as they could from the
story (see Appendix G for a rubric used for scoring and examples of appropriate
responses). They were also told that it was all right to use their own words and to not be
concerned with spelling or punctuation. This measure was used to see if there would be a
difference between the number of claims, thematic or worldviews and the number of
direct and indirect effects. I expected that the recall from the training group would be
superior and more focused on the text that they had read.

The essay asked the participants to give us their opinion on whether research on
improving science education was important (see Appendix H). They were asked to link it
to their own experiences and whether it contributed to society as a whole. In the text
several of these themes were touched on but not in these exact words. I wanted to see if
the groups differed much in their general reaction to the research. I also expected that the
training group would be more likely to directly mention segments from the text to support
their claims. I also expected the non-training group to be less positive about the research.

Essays were also looked at for general quality and the inclusion of inferences.

The short answer questions were written for this study to produce direct examples
of recall of important segments from the text. I expected to find more thorough results
from the training group. In particular I asked about direct and indirect effects, structural
models, potentially missing variables in the research and main conclusions. The short
answers should provide evidence of the participants overall conclusions about the text
and their knowledge of the key themes in the story.
Scoring

First the recall was scored. The 1700 word text on Improving Science Education was broken down into 102 segments (please see Appendix A). Main idea units were kept as cohesive units. Each idea unit was scored once even if it was duplicated in the recall responses. Either verbatim or paraphrased recall was accepted. Previous research suggested that people tend to recall information in paraphrase rather than verbatim from (Lehman and Schraw, 2002). Units that were significant to more than one segment were attributed to whatever segment was closer in context or particular word use. For example if the word foundation was used in the recall then it would be matched to the segment that also used that word rather than others segments similar in context. (see Appendix G for the rubric).

One point was awarded to each segment. Thematic recall was also recorded when broad statements about the text were made that did not specifically match any of the 102 segments. For example a theme would be “They need to go on trips to observe scientists”. Intrusions were also noted. A rubric was produced to score the recall with examples noted (see Appendix G).

Next the causal diagrams were scored. This required an interpretation of the categories represented by the drawings. It was decided to separate the diagrams into outline form, causal diagrams that resembled the practice diagram and a broad category that included tree diagrams, matrices and flow charts. Diagrams also were scored for clarity and the number of direct and indirect effects. A holistic score was applied to each diagram. Causal diagrams from the tutorial group were expected to be clearer, more
accurate and contain more correctly identified direct and indirect effects (see Appendices B-F).

The essays were scored with a holistic score for quality 0-2 (see the rubric in Appendix H for an example of this criteria). They received one point for each segment directly from the text. They received a 1 or a 0 for agreeing or disagreeing with the question. Then I scored each essay for broad themes not directly from the text but resulting from the essay's questions about relating the research to their own experiences, especially those in school (see Appendix H). For example a theme from the essays was “from modeling to doctors they need the help of science”. The essays received one point for any intrusions. These would be false or odd statements not related to the text. The segments from the text were not scored as a point total and not tracked per segment.

The short answer questions were scored as follows. Question number one has two points for describing a structural model and how scientists use it. This is directly drawn from the text, segments 11-15. The second question was scored with three points, one to describe a direct effect, one for an indirect effect and one for a sample of each. This question is from segments 15-23 however it also appears throughout the story.

Question number three was harder to score because it asks if the participant can think of any other variables that should be researched. I awarded a 1 or a 0, rather than track the number of variables that might be listed. Question four asked the participant what the main conclusions are from the story. This was scored on a scale of 0-2, indicating no response or poor and 2 indicating one or more of the important conclusions (see Appendix I).
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CHAPTER FOUR

RESULTS

I examined the results of four outcome measures that included both parametric and non-parametric analyses. Parametric tests were conducted on interval and ratio scale scores, including the number of claims, holistic quality of answers, thematic recall. I also conducted non-parametric tests (the Mann-Whitney U) to measure the clarity, number of styles and amount of data reported in the drawing measures. All statistical significance tests were conducted at the $\alpha = .05$ level unless otherwise noted.

Recall

A rubric was created to measure idea units, themes, and intrusions that occurred during the recall task. Results of the recall test yielded three scores, including the total number of idea units recalled from 102 possible units, the number of themes generated during recall, and the number of intrusions (see Appendix G). The difference between the training and non-training groups using the total recall score was significant, $t(60) = -2.57$. Table 6 shows that the mean of the training group was 1.96 idea units higher than the non-training group. The t-tests for the theme and intrusion scores did not differ significantly from one another. Thus training resulted in better recall of idea units, but training had no impact on the production of thematic statements or intrusion errors.
Essay

A rubric was created for the essay scoring. The rubric identified three measures: idea units, thematic statements, and number of intrusion errors. Scores for these measures were analyzed using t-tests. Results indicated that there were no significant differences between the training and non-training groups on any of these measures.

In addition, Mann-Whitney U tests were conducted on the holistic score for the essay (described in Appendix H). The holistic score was generated by ranking the holistic quality of the essay as being high, medium, or low. The mean rank for the training group was 34.03; the mean rank for the non-training group was 28.97. Thus, individuals in the training group were ranked higher on the quality of their essay than individuals in the non-training group. However, this difference was not statistically significant, p > .20. While the holistic quality of the essays may not have statistically differed for the two groups, some apparent differences in the essays existed. For example, the training group referenced idea units from the text more consistently than the non-training group.

Drawings

The drawings were examined for factual information as well as evidence that the training impacted conceptual understanding of causal diagram construction. A rubric was created to measure a series of variables (see Appendix B) that were then assessed using parametric and non-parametric statistics. Of particular importance in determining whether a successful diagram was created were the idea units; such as the four direct effect variables, the five predictor variables, and the three indirect effect variables. Means and standard deviations are reported in Table 6.
The essay, about improving science achievement, contained specific statements that included important predictors for improving science achievement. These predictor variables described events that would either directly or indirectly improve science achievement. The complexity of information presented in this text makes it an excellent example of why causal diagrams are useful.

Separate t-tests were conducted on correctly identified direct effects, indirect effects and predictor variables. No significant differences were found between the training and non-training group for the direct effect, $t(60) = -1.156$. Further the training and non-training groups did not differ on the number of indirect effects, $t(60) = -1.162$. In contrast, the predictor variable measurement revealed significant differences between the training group and the non-training group, $t(60) = -2.028$. These findings suggest that training helps individuals remember more predictors of academic achievement, but does not help them remember whether predictors are direct or indirect effects.

Mann-Whitney U tests for interval ranks were conducted to measure clarity, number of styles, and amount of information in the drawings as outlined in the drawing rubric (see Appendix B). The training group achieved significantly higher clarity scores (mean rank= 40) than the non-training group (mean rank=23), Mann-Whitney $U = 217$. For the styles score, the training group achieved significantly lower scores, with a mean rank of 22.50, than the non-training group which had a mean rank of 40.50, Mann-Whitney $U = 201.50$. This finding indicates that the non-training group used a wider variety of styles than the training group. This suggests that the training was effective in producing more appropriate and consistent causal diagrams. Finally, the amount-of-data score, revealed significant differences between the training (mean rank=26) and the non-
training group (mean rank = 37), Mann-Whitney U = 310.00. These results suggest that the non-training group included more non-critical information in their drawings as compared to the training group.

Short Answers

Results from the short answer test were split into six separate scores according to a rubric (described in Appendix I). These include scores for questions 1 through 4, a total score based on the composite of questions 1 through 4, as well as the number of inferences generated during the short answer task. The composite score was expected to be the most important measure of the effectiveness of training on performance as this score provides the most reliable estimate of overall performance. The difference between the training and non-training groups for the composite score was significant, $t$ (60) = -2.062, indicating that training was effective (see Table 6 for mean and individual scores). Individual t-tests on each of the four questions revealed that the training group outperformed the non-training group on questions 1 and 2, but not on questions 3 and 4. The t-tests for the number of inferences generated within the short answers were not significant.
CHAPTER FIVE

MAIN GOAL OF RESEARCH

The main goal of this study was to examine the influence of instruction, in particular the effectiveness of strategic training in the use of causal diagrams. Causal diagrams are pictures with embedded text elements. According to the Integrated Model of Text and Picture Comprehension (Schnotz and Bannert, 1999) this type of graphic display composed of text and pictures is simultaneously processed. Graphical displays appear to facilitate the recall of expository information, however not consistently. Therefore a brief instructional period would allow the students to understand the purpose of the graphic and allow the learner to create an integrated mental model of the concept.

A causal diagram explains the relationships between cause and effect variables within a structural model. In a way, a causal diagram is simply an equation that uses words and arrows to express causality. Expressing a complex concept appears to be easier to remember when a graphical method is used rather than using traditional prose.

Summary of Hypotheses and Research Questions

I implemented a brief strategic training module that helped students to understand the purpose of a causal diagram, the proper method of interpreting such a diagram and also the concept of indirect and direct effects. I hypothesized that the strategic training would result in superior recall, deeper comprehension and the creation of an integrated
mental model. The students who were trained in the use of causal diagrams were expected to create superior and more organized causal diagrams than the group that received no training. I asked the students do a brief uncued recall, an essay and four short questions. I expected direct recall of the text segments, comprehension of the goal and main idea of the story and broad thematic statements that might include the information or be completely unrelated to the text on science achievement. I expected to see more statements that were less directly referenced to the story in all the outcome measures produced by the non training group.

Data Results that Support and/or Refute Each Hypothesis

The data generally supported the hypothesis that training improves learning. There were a variety of positive gains due to training and no negative effects, although in some cases the training had no effect on performance. The recall was superior for claims directly related to the story from the training group. The non training group produced more thematic claims. The training groups’ drawings were clearer and showed greater cohesiveness in their organization and concept. Greater recall of predictor variables, indirect and direct effects was produced by the training group. The non training group did produce more information in their drawings, they were more likely to record facts that were not directly related to the direct and indirect effects preeminently mentioned in the story. Therefore it appears that the training group was better able to focus on the text.

The essay did not produce any real differences in idea units, themes, and holistic quality. Neither group showed real differences positive or negative to the research question in the science text.
The short answers supported the hypothesis that the training group showed better performance than the non-training group on questions 1, 2, and 4. The first question required the student to define the term and purpose of structural models. This concept is closely associated with the production of mental models. The training group was better able to answer this correctly. The second question was designed to establish whether the critical definition of the role of direct and indirect effects was retained by the students. Both questions one and two depended on recall of factual information. Finally, the students in the training group were better able to identify the main conclusions from the text. The difference between the training and non-training groups using the total recall score was significant. The total recall score was produced from a composite of all four questions and included the number of inferences drawn. The mean of the training group was higher than the no-training group. The training group outperformed the no-training group significantly on questions 1 and 2, but not on questions 3 and 4. The number of inferences generated was significant which supported my hypothesis that the causal diagramming of the information improved recall and facilitated deeper comprehension.

General Conclusions

Students need to see examples of graphics. They do far better in producing a graphic of variables when they are shown an example and when the example is explained in a meaningful way prior to studying it. It appears that students will follow a format when the purpose is apparent to them and when the learning benefits are presented to them. Students have widely disparate ability when it comes to producing an organized chart, table or graphic that clearly features important elements of an expository text.
Training appears to simplify the task and provide an uncomplicated and clearer template to work from.

Students that did not see an example either produced a haphazard combination of styles or were able to produce a comprehensive organized list of variables that may have included many more than the key effects emphasized in the text. In general the non training group produced more complex and less clear drawings. They tended to put more details down and had a less clear hierarchical structure to their drawings. They also tended to use pictorial elements like stick figures to represent students rather than words.

The recall of the training group demonstrated that they remembered more idea units specific to the text. Therefore more learning occurred in the training group. Training in the use of a causal diagram to describe scientific models may have impacted these questions producing better results. However it could also be that the non training group just did not know what facts to emphasize without the benefit of a brief instruction period. This shows a clear advantage for instruction in the use of graphics.

Theoretical Implications

The Integrated Model of Text and Picture Comprehension (Schnotz and Bannert), (see Figure 2) provides a descriptive road map on how working memory is facilitated when picture and text elements may be processed simultaneously. An integrated mental model can then be created through the linking and interlacing of both the picture information as well as the verbal information. In the IMTPC, the depictive branch and the verbal branch process their respective information, however the branches share the processing and exchange the necessary conceptual integration. This complementary
encoding of information creates an integrated mental model which is more effectively stored in long term memory.

Students who understand the strategies to employ when using a causal diagram are better prepared to focus their learning and alleviate bottlenecks in their own working memory. The information is compacted into a chunk of data and this data is then simultaneously processed by both the depictive and verbal branches into a deeper level of comprehension.

The Scevak, Moore and Kirby (1993) findings are consistent with my research results. Training does improve recall. Not only that, the use of adjunct aids is vastly facilitated by brief instruction. It seems that there is an assumption that students have been trained in the use of graphical aids, however research such as Shah and Hoeffner, and the Scevak et al. study seems to suggest that this assumption is incorrect and that if training is performed then graphical aids can provide a definite and measurable improvement to recall and general instructional performance. If the use of graphics in instruction is not utilized, the student is surely at a disadvantage especially considering the evidence that "pictures are worth a thousand words". It appears that educators need to teach students how to read the pictures or at least explain how these diagrams, pictorial and depictive representations are designed to be used.

The present findings are consistent with the IMTPC because they suggest that pictorial representations improve learning when students are training to understand those representations, because working memory can more easily process the chunked graphic illustrations and then interconnect the verbal text elements included within. The Scevak
et al. study clearly showed the advantages that students have when the use and practice of graphical aids is clearly demonstrated and emphasized.

Limitations of the Study

The number one limitation that I observed was not being able to measure delay. In particular in the Scevak, Moore and Kirby study (1993) they assessed whether the map using strategies remained apparent three weeks later with a different text and a different map. In addition I do not think that enough time was allowed for the reading and drawing. Several students in both conditions reported that they wanted more time to read and draw. It appears that a 1700 word text might require up to a half hour, which would have added at least ten minutes to the study.

I also determined that describing the task as a drawing was a problem because some students interpret drawing in the same manner as cartooning. Perhaps a different description of the task might have produced a different sort of diagram from the non training group.

It would certainly be interesting to conduct this experiment and then test students later on with new material to assess whether these skills are transferable and whether the notion of causality is linked to diagramming. In the IMTPC (see Figure 2) the text and picture elements are processed simultaneously but utilize different cognitive resources. If students learn to diagram or graph, then they could restore working memory capacity when studying complex information just as a computer could rely on a different drive for additional memory resources.
Educational Implications

The most obvious implication for education is that training in the construction of causal diagrams, if it is strategic, improves learning of the diagrams and comprehension of related text information. It was apparent from this study that students do not come equipped with the same amount of ability to graph or pictorially represent a series of variables (or any kind of information). For students who do not receive training, the production of a graphic can be a real struggle. My results indicate that even with a modest instructional intervention of less than 15 minutes, students' construction of diagrams and text comprehension can be facilitated. Therefore teachers should invest a brief amount of instructional time devoted to students' understanding of graphic displays prevalent in their textbooks and curriculum materials. As was evident in their drawings, students who received training were more successful in creating effective causal diagrams. Those students without training were able to list the correct variables on the diagram but were not able to create a tight chain of cause and effect variables. Some students who did not receive training appeared to not understand what to do with the information.

This study reinforces the research that shows that picture and text comprehension work together to benefit learning. It also shows that a wide range of learners can be successful trained in the production and comprehension of graphical charts and diagrams to assist in learning difficult and complex chains of causality. As the Shah and Hoeffner (2002) studies show there is a wide gap between graphical literacy needs and reality.

The IMTPC from Schnotz and Bannert provides a fascinating explanation into the workings of cognitive processes. If this is a type of comprehension load sharing, then it is
Like your computer using more than one drive to build a large file. The ability to produce a simple picture or pictorial based diagrams may vastly enhance cognitive functions. To use another computer metaphor although I know that the brain/mind is very different, the diagram allows the mental model to be created simply (like a flash picture) and then integrated into existing schema. In a sense the thought or fact comes in whole and is later processed and portioned off to the necessary departments in memory.

Directions for Further Research

It is perhaps obvious that the role of graphics in learning has been studied but there are many questions. Future research needs to more accurately determine how much graphics help and where their introduction creates overload. The ability to create graphics on the computer has not necessarily helped learning. The graphical laws should be more closely adhered to especially by textbook and instructional designers. I would like to investigate whether teachers can be assisted in the use of causal models when they are teaching, and whether there is a benefit to teaching students the basics of diagramming for subjects like social studies and science. It would be interesting to see if graphical literacy skills generalize to improvement in note taking and testing skills.
Improving Science Education

What makes someone good at science? It was once thought that being a good science student was the domain of boys, or perhaps "exceptionally smart boys." But recent studies indicate that girls do just as well in science if given the same encouragement and training. Moreover, students do not need to be whiz kids to excel at science. Rather, they need parental support, a good understanding of basic concepts, and plenty of quality instruction.

In the rest of this article, we discuss what educational researchers know about improving science education. A number of important predictor variables (i.e., variables in a statistical study that predict science achievement) have been studied thus far, and there is evidence that some of these variables are extremely important. The five most important variables are parental education, prior science achievement, instructional time, self-efficacy for learning science (i.e., the extent to which the student feels confident about learning science), and use of appropriate learning strategies.

Direct and Indirect Effects

Researchers are keenly interested in what variables are the best predictors of science achievement. To help them answer this question, researchers typically propose a structural model of how different predictor variables are related to each other and test the adequacy of the model using a large national sample. It is important to understand that these models are hypothetical in nature; that is, they are tentative model until they are supported by data.

There are two main types of "effects" in these structural models, which we refer to in this article as direct effects and indirect effects. A direct effect occurs when a change in one variable causes a direct change on a second variable. For example, a student’s prior science achievement has a strong direct influence on later science achievement. The more a student has learned in the past, the better he or she will do in future science classes. This relationship holds true regardless of other variables.

An indirect effect occurs when a change in one variable causes a change in a second variable, which in turn, causes a change in a third variable. For example, gender does not have a direct influence on a student’s science achievement, but it does influence instructional time, which in turn, influences science achievement. Thus, a direct effect involves two variables, where the first variable causes a change in a second variable. An indirect effect involves least three variables, where variable 1 affects variable 2, and variable 2 affects variable 3, without a direct effect between variable 1 and variable 3.

Direct Effects on Science Achievement

There are four important direct effects on science achievement. These include parental education, prior science achievement, instructional time, and learning strategies. Parental education is very important because it affects achievement in several ways. One is that parents value achievement because they have reached high levels of achievement. Second, better-educated parents may be better able to assist their children. Third, parents may be better able to afford special science opportunities for their children. Prior science achievement is important as well because it provides the informational foundation for subsequent science learning. The more you know about science, the easier it is to learn new concepts. Instructional time also plays a role. The more instructional time students have in science, the higher their learning. Generally speaking, twice as much time translates into twice as much learning. Last, learning strategies facilitate science
learning, especially complex learning strategies that help students get deeper meaning. Examples of deeper strategies are integrating main concepts and relating new information to what the student already knows.

Overall multiple factors contribute directly to science achievement. Currently, there is debate about how much each variable influences science achievement. Experts really don’t know, though they assume that each variable makes an important separate contribution to prediction of current science achievement. Our best guess is that the three most important direct effects are parental education, prior achievement, and instructional time.

Other Direct Effects

There are other direct effects between variables worth our attention. For example, parental education directly affects student interest, self-efficacy for learning science, and prior achievement. Many experts feel that parental education is one of the most important variables in science achievement. Highly educated parents appear to motivate and encourage their children in a manner that has many positive influences on later achievement. In addition, gender directly affects self-efficacy for learning science and instructional time. Females generally report less self-efficacy and receive less instructional time than male students. The potentially negative effects of gender can be offset through encouragement and giving equal opportunities in the science classroom.

In contrast, some variables have no effect even when we might expect them to. For example, instructional quality does not appear to affect science achievement. The lack of a relationship between these variables surprises many people, yet has been replicated many times. Experts agree that it is the amount of instruction, rather than the quality of the instruction, that is important. More research is need on this topic because sometimes statistical studies fail to detect effects that are really there (i.e., the researcher draws the wrong conclusion). Most people also are surprised to learn that interest does not affect current science achievement. Although interest makes learning more fun, it does not lead to more learning.

Indirect Effects on Science Achievement

There are three important indirect effects. These include an indirect effect of parental education on current achievement as mediated by prior achievement, an indirect effect of gender on science achievement as mediated by instructional time; and an indirect effect of self-efficacy on achievement as mediated by learning strategies. The first of these three indirect effect states that better-educated parents have children with higher levels of prior science achievement, which leads to higher levels of current science achievement. The second indirect effect suggests that gender leads to differences in instructional time, which leads to differences in current achievement. It is well known that females receive less instructional time in science than males, which decreases achievement among females. The third indirect effect indicates that students with higher self-efficacy are more likely to use effective learning strategies, which leads to higher levels of science achievement. High self-efficacy students tend to use a greater number of strategies, as well as more sophisticated strategies such as integrating main ideas.

In summary, research reveals that a number of variables affect current science achievement. Some have a direct effect; some have an indirect effect; and some have both (e.g., parental education). The most important of these variables are parental

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education, prior science achievement, and instructional time. Important, but secondary
variables, are student self-efficacy, strategy use, and gender.

**Ways to Improve Science Education**

The research summarized above suggests four ways to improve science education,
including parental education, early success for students who are at risk for low science
achievement, more instructional time, and strategy training that enables students to
generate a deeper understanding of the material. Improving parental education may
sound odd at first. After all, researchers know that well-educated parents have children
who do well at science. The problem, however, is with less-educated parents. Science
teachers need to help these parents understand the importance of science, as well as the
role that parents play in modeling science education. Helping parents feel comfortable
with science might be just as important as helping their children!

Early success for at-risk students is a crucial component of science education.
Students who struggle while young will not have the necessary skills and knowledge base
to succeed at science as they progress through middle and high schools. Several
solutions have been tried so far, including more instruction, supplemental instruction,
greater use of older student tutors, and science tutorials on websites. Like other areas of
education, the earlier the intervention, the more effective it is, and the better prepared the
student is to succeed at each new level. Early interventions seem especially important for
females who typically are given less parental support than boys.

Research highlights the need for more instructional time. Two aspects of science
instruction are important. One is classroom instruction and related laboratory
experiences. Research indicates that students learn to think like scientists by acting like
scientists; that is, conducting experiments, analyzing data, and evaluating solutions.
Students cannot learn to be scientists without laboratory experiences. Of equal
importance are quality field experiences in which students can apply their science
learning in real-world settings. Both components are essential for children of all age.

Strategy training is another crucial area. Many students lack an adequate strategy
base and the knowledge to use these strategies effectively. This is especially true of what
researchers call **shallow** versus **deeper** strategies. Shallow strategies are things like
taking verbatim notes and memorizing facts. Deeper strategies are things like identifying
main concepts and integrating information into a summary table or diagram. Good
learners use more strategies than poor learners, and more of the strategies used by good
learners are deeper strategies. Researchers know that strategy instruction is quite
effective at helping low-achieving students develop a bigger repertoire of strategies.
Without such a repertoire, students may lack the skills to learn science even if they are
motivated and work hard.

**A Brighter Future**

Researchers have provided us with useful knowledge about science achievement.
Thanks to public concern, more schools are emphasizing science education, and spending
additional money to hire science specialists. This means more instructional time and
better field experiences for students of all ages, and higher levels of science achievement.
Females are finely getting a fair chance to participate on an equal footing with boys. The
secret to success in science at the national level is to get parents involved and to provide
all students with an excellent knowledge base and a wealth of laboratory and field
experiences. Schools already are moving in that direction. As a result, the future looks bright for science education.
1. What makes someone good at science?

2. It was once thought that being a good science student was the domain or boys, or perhaps "exceptionally smart boys."

3. But recent studies indicate that girls do just as well in science if given the same encouragement and training.

4. Moreover, students do not need to be whiz kids to excel at science.

5. Rather, they need parental support, a good understanding of basic concepts, and plenty of quality instruction.

6. In the rest of this article, we discuss what educational researchers know about improving science education.

7. A number of important predictor variables (i.e., variables in a statistical study that predict science achievement) have been studied thus far and there is evidence that some of these variables are extremely important.

8. The five most important variables are parental education, prior science achievement, instructional time, self-efficacy for learning science (i.e., the extent to which the student feels confident about learning science), and use of appropriate learning strategies.

Direct and Indirect Effects

9. Researchers are keenly interested in what variables are the best predictors of science achievement.
12. To help them answer this question, researchers typically propose a structural model of how different predictor variables are related to each other and test the adequacy of the model using a large national sample.

13. It is important to understand that these models are hypothetical in nature; that is, they are tentative until they are supported by data.

14. There are two main types of "effects" in these structural models.

15. which we refer to in this article as direct effects and indirect effects.

16. A direct effect occurs when a change in one variable causes a direct change on a second variable.

17. For example, a student's prior science achievement has a strong direct influence on later science achievement.

18. The more a student has learned in the past, the better he or she will do in future science classes.

19. This relationship holds true regardless of other variables.

20. An indirect effect occurs when a change in one variable causes a change in a second variable, which in turn, causes a change in a third variable.

21. For example, gender does not have a direct influence on a student's science achievement, but it does influence instructional time, which in turn, influences science achievement.

22. Thus, a direct effect involves two variables, where the first variable causes a change in a second variable.
23. An indirect effect involves least three variables, where variable 1 affects variable 2, and variable 2 affects variable 3, without a direct effect between variable 1 and variable 3.

Direct Effects on Science Achievement

24. There are four important direct effects on science achievement. These include parental education, prior science achievement, instructional time, and learning strategies.

25. Parental education is very important because it affects achievement in several ways.

26. One is that parents value achievement because they have reached high levels of achievement.

27. Second, better-educated parents may be better able to assist their children.

28. Third, parents may be better able to afford special science opportunities for their children.

29. Prior science achievement is important as well because it provides the informational foundation for subsequent science learning.

30. The more you know about science, the easier it is to learn new concepts.

31. Instructional time also plays a role.

32. The more instructional time students have in science, the higher their learning.

33. Generally speaking, twice as much time translates into twice as much learning.

34. Last, learning strategies facilitate science learning.
especially complex learning strategies that help students get deeper meaning.

Examples of deeper strategies are integrating main concepts and relating new information to what the student already knows.

multiple factors contribute directly to science achievement

Currently, there is debate about how much each variable influences science achievement.

Experts really don’t know, though they assume that each variable makes an important separate contribution to prediction of current science achievement.

Our best guess is that the three most important direct effects are parental education, prior achievement, and instructional time.

Other Direct Effects

There are other direct effects between variables worth our attention.

For example, parental education directly affects student interest, self-efficacy for learning science, and prior achievement.

Many experts feel that parental education is one of the most important variables in science achievement.

Highly educated parents appear to motivate and encourage their children in a manner that has many positive influences on later achievement.

In addition, gender directly affects self-efficacy for learning science and instructional time.

Females generally report less self-efficacy and receive less instructional time than male students.
The potentially negative effects of gender can be offset through encouragement and giving equal opportunities in the science classroom.

In contrast, some variables have no effect even when we might expect them to.

For example, instructional quality does not appear to affect science achievement.

The lack of a relationship between these variables surprises many people, yet has been replicated many times.

Experts agree that it is the amount of instruction, rather than the quality of the instruction, that is important.

More research is needed on this topic because sometimes statistical studies fail to detect effects that are really there (i.e., the researcher draws the wrong conclusion).

Most people also are surprised to learn that interest does not affect current science achievement.

Although interest makes learning more fun, it does not lead to more learning.

Indirect Effects on Science Achievement

There are three important indirect effects.

These include an indirect effect of parental education on current achievement as mediated by prior achievement.

an indirect effect of gender on science achievement as mediated by instructional time;
58. and an indirect effect of self-efficacy on achievement as mediated by learning strategies.

59. The first of these three indirect effect states that better-educated parents have children with higher levels of prior science achievement, which leads to higher levels of current science achievement.

60. The second indirect effect suggests that gender leads to differences in instructional time, which leads to differences in current achievement.

61. It is well known that females receive less instructional time in science than males, which decreases achievement among females.

62. The third indirect effect indicates that students with higher self-efficacy are more likely to use effective learning strategies, which leads to higher levels of science achievement.

63. High self-efficacy students tend to use a greater number of strategies, as well as more sophisticated strategies such as integrating main ideas.

64. In summary, research reveals that a number of variables affect current science achievement

65. Some have a direct effect; some have an indirect effect; and some have both (e.g., parental education).

66. The most important of these variables are parental education, prior science achievement, and instructional time

67. Important, but secondary variables, are student self-efficacy, strategy use, and gender.

Ways to Improve Science Education
The research summarized above suggests four ways to improve science education, including parental education, early success for students who are at risk for low science achievement, more instructional time, and strategy training that enables students to generate a deeper understanding of the material.

Improving parental education may sound odd at first. After all, researchers know that well-educated parents have children who do well at science.

The problem, however, is with less-educated parents. Science teachers need to help these parents understand the importance of science, as well as the role that parents play in modeling science education.

Helping parents feel comfortable with science might be just as important as helping their children!

Early success for at-risk students is a crucial component of science education.

Students who struggle while young will not have the necessary skills and knowledge base to succeed at science as they progress through middle and high schools.

Several solutions have been tried so far, including more instruction, supplemental instruction, greater use of older student tutors, and science tutorials on websites.

Like other areas of education, the earlier the intervention, the more effective it is, and the better prepared the student is to succeed at each new level.
Early interventions seem especially important for females who typically are given less parental support than boys.

Research highlights the need for more instructional time.

Two aspects of science instruction are important.

One is classroom instruction and related laboratory experiences.

Research indicates that students learn to think like scientists by acting like scientists; that is, conducting experiments, analyzing data, and evaluating solutions.

Students cannot learn to be scientists without laboratory experiences.

Of equal importance are quality field experiences in which students can apply their science learning in real-world settings.

Both components are essential for children of all ages.

Strategy training is another crucial area.

Many students lack an adequate strategy base and the knowledge to use these strategies effectively.

This is especially true of what researchers call shallow versus deeper strategies.

Shallow strategies are things like taking verbatim notes and memorizing facts.

Deeper strategies are things like identifying main concepts and integrating information into a summary table or diagram.

Good learners use more strategies than poor learners, and more of the strategies used by good learners are deeper strategies.
92. Researchers know that strategy instruction is quite effective at helping low-achieving students develop a bigger repertoire of strategies.

93. Without such a repertoire, students may lack the skills to learn science even if they are motivated and work hard.

A Brighter Future

94. Researchers have provided us with useful knowledge about science achievement.

95. Thanks to public concern, more schools are emphasizing science education and spending additional money to hire science specialists.

96. This means more instructional time and better field experiences for students of all ages.

97. and higher levels of science achievement.

98. Females are finely getting a fair chance to participate on an equal footing with boys.

99. The secret to success in science at the national level is to get parents involved and to provide all students with an excellent knowledge base and a wealth of laboratory and field experiences.

100. Schools already are moving in that direction.

101. As a result, the future looks bright for science education.
APPENDIX B
In this part we want you to draw your own causal diagram while you read the text. Try to include all of the variables listed and label them as direct or indirect effects. Don’t worry about neatness, just do the best you can.

Scoring Rubric

<table>
<thead>
<tr>
<th>Direct Effects</th>
<th>Indirect Effects</th>
<th>Predictor Variables</th>
<th>Clarity</th>
<th>Styles</th>
<th>Number of pages</th>
<th>Hierarchy</th>
<th>Amount of Info</th>
</tr>
</thead>
<tbody>
<tr>
<td>*Max=4</td>
<td>**Max=3</td>
<td>***Max=5</td>
<td>1=low, 2=medium, 3=high</td>
<td>1, 2 or 3</td>
<td>1 or 2</td>
<td>1=yes, 0=no</td>
<td>1=low, 2=medium, 3=high</td>
</tr>
</tbody>
</table>

* parental education, prior science achievement, instructional time, and learning strategies
**indirect effect of parental education on current achievement as mediated by prior achievement, an indirect effect of gender on science achievement as mediated by instructional time; and an indirect effect of self-efficacy on achievement as mediated by learning strategies
*** parental education, prior science achievement, instructional time, self-efficacy for learning science (i.e., the extent to which the student feels confident about learning science), and use of appropriate learning strategies.

- *Clarity* was determined by neatness, number of styles, clear labeling
- A *style* was for example drawn as a causal diagram, a second style would be an outline and a third a tree diagram, some participants used more than one to illustrate the information from the story.
- *Hierarchy* was determined by whether the diagram or notes had a clear chain of causation and an order of importance for the variables
- *Amount of information* was the actual physical amount of data notated on the sheet

Please see Appendices C-F for sample
Draw while you read

In this part we want you to draw your own causal diagram while you read the text. Try to include all of the variables listed and label them as direct or indirect effects. Don’t worry about neatness, just do the best you can.
Draw while you read

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Sample Drawing

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Sample Drawing

Draw while you read

In this part we want you to draw your own causal diagram while you read the text. Try to include all of the variables listed and label them as direct or indirect effects. Don't worry about neatness, just do the best you can.
Draw while you read

In this part we want you to draw your own causal diagram while you read the text. Try to include all of the variables listed and label them as direct or indirect effects. Don't worry about neatness, just do the best you can.
RECALL INSTRUCTIONS

In this part we want you to recall as much as you can from the story IMPROVING SCIENCE EDUCATION. Please try to remember as much as possible, even if you have to put it into your own words. Don’t worry about spelling or punctuation.

Scoring Rubric

<table>
<thead>
<tr>
<th>Segments</th>
<th>Themes</th>
<th>Intrusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum 102</td>
<td>One point per theme</td>
<td>One point</td>
</tr>
</tbody>
</table>

An example of a claim would be “Five main variables were found to affect achievement: prior science knowledge, educated parents, effective time, self efficacy etc.” (1 point) or “It was said that children would often do better if that had previous exposure to science and it was also said that it is not the quality of the presentation it is the quantity”. (2 points) see Appendix A for a breakdown of the scoring segments.

A theme for example would be “What I remember the most about the article that I just read was the perplexing correlation between the learning of boys compared to girls”. I expected to find more themes among the non training group.

An intrusion would be “just because someone is more motivated to learn does not mean that more learning will occur”. This is the opposite of the message from the text, I expected to find more if any intrusions in the non training group.
Instructions for Essay

In this part, we want you to tell us whether you think the research on improving science education is important. Please state whether it is important or unimportant, and tell us why you think so. Try to link this research to your own school experiences. In addition, comment on whether you personally support this kind of research (e.g., does it contribute to society as a whole)?

Scoring Rubric for Essays

<table>
<thead>
<tr>
<th>Claims</th>
<th>Positive or negative answer</th>
<th>Holistic quality</th>
<th>Themes</th>
<th>Intrusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max=102 possible segments from the text, see samples*</td>
<td>Did they support the research, was it important?</td>
<td>0=low, 1=medium, 2=high general quality of essay</td>
<td>See samples**</td>
<td>totally false or odd statement</td>
</tr>
</tbody>
</table>

Themes would be for example "every kid should be given the chance to learn science." or "I don't find science to be fun but I like to learn" or "without science our world would be prehistoric"

For the claims an example would be "Science education is important when it starts with better educated parents" or "proper research can identify which variables influence science learning achievement and suggest ways that variables can be controlled and influenced." I did not track the segment number I just gave them a point total for claims from the text.

A good essay would have direct reference to the text, be well written and answer all the parts of the essay. A medium essay would have one or two references to the text and
answer part of the essay question. A low score would be poorly written and answer partially or not at all with one or no references to the science text.
In this part we want you to answer the short questions below.

Please use complete sentences. Acceptable answers are in italics.

1. What is a structural model and how do researchers use it? (2 points) A structural model is when researchers hypothesize about cause and effect and then set up a model to test the hypotheses.

2. What is a direct effect? How does it differ from an indirect effect? Give an example from the text for each. (3 points) A direct effect is when one factor causes a change in another factor. Parental ed → science achievement. An indirect effect is when there is more than 2 factors and the second factor mediates gender → science achievement.

3. Can you think of other variables that were not included in this research that should be? (0 or 1) No=0, Yes=1.

4. What main conclusions can we draw from this article? (2 points) Science achievement is not static. It can be improved parental education, self efficacy, instructional time and lab experience all directly effect science education.
Figure 3
Practice Diagram
Causal Diagram: Factors that Affect Overall Fitness

Direct Effect: A change in one variable causes a direct change on a second variable [There are 3 direct effects shown above].
Indirect Effect: A change in one variable causes a change in a second variable, which in turn, causes a change in a third variable. [There is 1 indirect effect shown above].
INSTRUCTIONAL SEQUENCE

Orientation Phase
1. Model the importance of Causal Diagram (CD)
   - explain why CDs are important
     - provide “systems level” understanding of complex processes
     - reveals “causal” interrelationships among variables
   - strengths and weaknesses
     - strengths
       - provides “big picture” or “causal model” of system
     - weaknesses
       - hypothetical in nature (proposed CD could be wrong)
       - very difficult to test empirically

Informational Phase
2. Explain flow of information
   - includes elements that correspond to variables of interest
   - left to right (implies temporal causality)
     - introduce concept of “upstream” and “downstream” variables

3. Explain direct and indirect effects
   - direct effect: one variable causes change in a second variable
     - Example 1: smoking causes lung cancer
     - Example 2: driving too fast (or recklessly) causes car accidents
   - indirect effect: one variable causes an effect on a second variable, which
     causes an effect on a third variable, even though variable one does not directly
     cause a change in variable 3
     - Example 1: smoking indirectly causes the need for more respiratory nurses
     - Example 2: fast driving indirectly causes higher insurance rates
   - each direct and indirect effect varies in importance (pathways are sometimes labeled with correlations)

Integration Phase
4. Extracting main themes from causal diagram
   - identify several main themes from CD
     - parental education impacts many “downstream variables”
     - multiple variables affect current science achievement (i.e., there are multiple direct and indirect effects)
     - some variables (e.g., instructional time) have no effect on current science achievement

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APPENDIX L
EXAMPLES OF DIRECT AND INDIRECT EFFECTS

A direct effect occurs when one variable causes change in a second variable.

- Example 1: smoking causes lung cancer
  
  Smoking $\rightarrow$ Lung Cancer

- Example 2: driving too fast (or recklessly) causes car accidents
  
  Fast Driving $\rightarrow$ Accidents

An indirect effect occurs when one variable causes an effect on a second variable, which causes an effect on a third variable, even though variable one does not directly cause a change in variable 3. Variable 2 is called the mediating variable because it mediates the relationship between variables 1 and 3.

- Example 1: smoking indirectly causes the need for more respiratory nurses
  
  Smoking $\rightarrow$ Illness (mediating variable) $\rightarrow$ Need for Nurses

- Example 2: fast driving indirectly causes higher insurance rates
  
  Fast Driving $\rightarrow$ Accidents $\rightarrow$ Higher Insurance Rates
Table 4

<table>
<thead>
<tr>
<th>Instruction</th>
<th>Non Instruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants read and sign their informed consent</td>
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</tr>
<tr>
<td><strong>Participants receive instruction on the use and construction of causal diagrams, this includes examples of direct and indirect effects</strong></td>
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</tr>
<tr>
<td>Participants receive a sample causal diagram to briefly study, this is then replaced inside their envelope before they remove the text and “draw while you read sheet”.</td>
<td>Participants do not receive a sample diagram, they are instructed to remove the text and attached “draw a causal diagram while you read sheet.”</td>
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</tr>
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<td>Participants get ten minutes for four short questions</td>
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</tr>
</tbody>
</table>

Integration of instruction plus a causal diagram constructed from the text should lead to a superior mental model, vastly facilitating comprehension and recall.

Result: Deeper Processing
Table 5

Strategic Training on how to use and construct a Causal Diagram

Step One: Read and sign your informed consent  ➔  Step Two: I am going to help you understand how to use and construct a causal diagram, we will spend about ten minutes

Step Three: I will show you an example
Step Four: I will identify elements that are essential to understanding the text
Step Five: I will explain why elements are placed  ➔  Step Six: I will show you examples of direct and indirect effects where they are and what the role of arrows are in a typical diagram
Step Seven: We will look at the practice diagram  ➔  Step Eight: Constructing a causal diagram should help you understand the text that you read, recall more efficiently and provide you with a mental model of the information.

Step Nine: You will be instructed to open your envelope and pull out the text portion and the single sheet, which instructs you to draw while you read. This should take about twenty minutes. Please sit quietly if you finish ahead of others. You can go back and add to your diagram but do not go on to any other materials in the packet.
Step Ten: At about 16-18 minutes I will remind you of the time remaining. Then at around 20 minutes if the majority have laid down their pens we will finish and place the text and the diagram inside your envelopes.
Step Eleven: Take out the remaining packet, which is stapled together. You will have 8-10 minutes per sheet but you must wait for the group to finish. Please sit quietly and do not skip ahead. First recall as much as possible. Do not to worry about punctuation, spelling etc. The next sheet is a general essay. The third and final sheet is four short questions that we designed to look for specific comprehension and deeper processing.

Purpose of the training: To help students comprehend, recall and integrate complex information. I predict that the strategic training will make it easier to remember complicated texts by illustrating a method that allows the learner to develop an accessible mental model that is the result of deeper levels of comprehension.

Training + Reading and Constructing a Causal Diagram = Integrated Mental Model/Greater Recall and Comprehension
Subjects
Participants used in the study will be selected from the undergraduate educational psychology research pool. These individuals receive course credit for their participation.

Purpose
The purpose of this research is to examine the effect of a causal diagram on recall and deeper understanding of an expository text. A causal diagram shows the relationships among a number of variables (see the attached figure). Previous research indicates that adjunct aids such as maps and summary tables increase learning; however, causal diagrams have not been investigated (Robinson, 2002). We predict that studying the causal diagram before reading will enhance recall of text information, as well as deeper processing necessary to synthesize information and generalize to new settings.

Methods and Procedures
Participants will read a 1,700 word expository text entitled Improving Science Learning with or without the causal diagram. Those in the causal diagram condition will be given the diagram prior to reading and allowed to study it for three minutes. Procedures in both groups will be identical thereafter. Participants will be given 12 minutes to read the story. Next, they will be given ten minutes to recall as much of the story as possible. After this, they will be given ten minutes to write a synthesis essay in which they respond to the question “Please explain why the research on improving science achievement is important.” Essays will be scored for the number of supported arguments and evidence using the criteria described by Lehman and Schraw (2002).

Risks/Benefits/Costs
Risks associated with the research are negligible. Benefits include an opportunity to earn course credit for their participation and learn about recent research on science education. The cost to subjects will be minimal. The cost to subjects is their time, which will be approximately 50 minutes.

Risk-Benefit Ratio
The benefits of this research outweigh the risks. Benefits include the opportunity to examine how working memory capacity influences reading comprehension. This information can inform text writers and instructional designers of ways to structure text to promote optimal comprehension by more readers. Risks are minimal.
Informed Consent

All participants are expected to be legal adults (18 or older). In addition, each will be informed as to the nature of the study prior to participating and have the right to withdraw at any time without penalty. Participants will read and sign the informed consent form prior to the start of the working memory tasks. The researchers will be responsible for obtaining the informed consent. The informed consent forms will be stored in a locked room in the College of Education building for at least 3 years after the completion of the study.
INFORMED CONSENT FORM

I am Anne M. Poliquin, a Masters student in the Department of Educational Psychology at the University of Nevada-Las Vegas and the primary investigator in this study. I am requesting your participation in a research project about effective reading. Participants will receive one research credit as incentive for participation.

Purpose: The purpose of this experiment is to examine the effective of adjunct aids during reading. This research can inform text writers and instructional designers of ways to organize text materials that lead to optimal understanding by readers.

Procedures: You will be asked to read a 1,700 word text on Improving Science Education. Then you will be given a test of what you learned. After everyone has finished, the researcher will explain the expected results of this study. The entire session should take approximately 1 hour to complete.

Confidentiality: All of the information collected will be kept strictly confidential. The information will be scored and recorded by the researchers. All data collected will be stored in locked files at an undisclosed location at UNLV for at least three years after completion of the study.

Consent: Your participation in this research is strictly voluntary. You will receive one hour research credit for your participation. You may ask any questions concerning the research before agreeing to participate or during the study. You also may withdraw from the project at any time without penalty if you do not wish to complete the interview process. Your signature certifies that you have read and understood the information presented. Further, by signing this statement I affirm that I am 18 years of age or older. If you have questions about your rights as a research participant that have not been addressed by the investigator, you may contact the UNLV Office for the Protection of Research Subjects, telephone (702) 895-2794.

______________________________ Date
Signature of Research Participant

Anne Poliquin
Gregory Schraw, Ph.D.

(702) 895-3253
(702) 895-2606
FIGURE 1: Model of Current Science Achievement

- Student Interest
- Gender
- Parental Education
- Self-efficacy For Science
- Prior Science Achievement
- Instructional Time
- Instructional Quality
- Learning Strategies

Direct Effect

Indirect Effect: Gender on Achievement
Figure 2 (Schnotz and Bannert, 1999)

A description of the Integrated Model of Text and Picture Comprehension

Fig. 1. Schematic illustration of an integrative model of text and picture comprehension.
Figure 3
Practice Diagram
Causal Diagram: Factors that Affect Overall Fitness

Direct Effect: A change in one variable causes a direct change on a second variable [There are 3 direct effects shown above].

Indirect Effect: A change in one variable causes a change in a second variable, which in turn, causes a change in a third variable. [There is 1 indirect effect shown above].
Table 1  Effectiveness in the use of graphics in instruction

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Methods/ Theories</th>
<th>Findings and Concerns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rieber (1990a, b)</td>
<td>Animated and static diagrams for science learning, 4th and 5th graders</td>
<td>Animated graphics improved scoring but only when provided with guided practice. Static displays did not improve learning as compared to text alone</td>
</tr>
<tr>
<td>Mayer (1989a, b)</td>
<td>Derived from Dual Coding, application questions</td>
<td>Science diagrams, whose purpose was the forming a coherent mental model for low level subject matter (science) undergraduates- only labeled illustrations improved learning of explanatory information and problem solving</td>
</tr>
<tr>
<td>Mayer and Gallini (1990)</td>
<td>Explanative texts with and without illustrations, some multimedia use</td>
<td>Explanative were more effective Improved problem solving and conceptual learning for low but not high level learning Perhaps not necessary for high learners?</td>
</tr>
<tr>
<td>Shah and Hoeffner</td>
<td>Shah and Hoeffner, (2002) Graphical literacy skills are necessary and should be taught in the context of science and social science. Errors in graph comprehension may occur if there is inconsistent or inadequate prior knowledge (Shah, 1995) Shah and Shellhammer (1999) found that less skilled graph users had more difficulty in identifying trends than did more skilled users</td>
<td>1. Choose format according to communication goal. 2. Use multiple formats to communicate same data Use best visual dimension i.e. to convey metric info. (Simkin and Hastie, 1986) Format is function of task Use animation with caution Reduce working memory loads Choose colors carefully 3D is okay unless precise metric info is needed Aspect ratio and data density should be chosen carefully-graph size Graphs and Text should be consistent</td>
</tr>
</tbody>
</table>
Table 2 Properties of Graphic Displays

<table>
<thead>
<tr>
<th>Charts</th>
<th>Diagrams</th>
<th>Pictorial</th>
<th>Geographic Maps</th>
<th>Matrices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Show position and relationship of elements, text based with some graphics for organization</td>
<td>Use of boxes and arrows, text in boxes, may use pictorial elements, commonly used for labeling parts</td>
<td>Illustrative, subjective, decorative, depends on preexisting conceptions</td>
<td>Holistic, combines text with illustrations, may be considered decorative</td>
<td>Text based, more like an equation or outline</td>
</tr>
</tbody>
</table>
Table 3 Overview of primary theories that deal with text and graphic processing

<table>
<thead>
<tr>
<th>Theory</th>
<th>Main Assumptions</th>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dual Coding</td>
<td>Verbal and visual processing is separate but connected, different units of representation, logogens and imagens</td>
<td>Graphics work together with text to improve learning. Better allocation of memory resources because cognitive work is divided</td>
<td>Separate channels, no evidence for such cognitively How do they work together and coordinate tasks</td>
</tr>
<tr>
<td>Conjoint Retention</td>
<td>Compatible with Dual Coding and visual argument</td>
<td>Maps are encoded as holistic units, improve recall because they are processed as a big chunk</td>
<td>Applies to maps primarily, derives from Dual Coding ideas about two separate channels</td>
</tr>
<tr>
<td>Visual Argument</td>
<td>Graphics provide better recall and influences processing for visual and spatial elements</td>
<td>Visuo-spatial properties use Gestalt properties to improve the processing of text and graphics</td>
<td>Does not account for why text can be recalled better, no real evidence, also came from Dual Coding</td>
</tr>
<tr>
<td>IMTPC</td>
<td>Text and pictures are processed simultaneously and cross referenced semantically and propositionally</td>
<td>Integration creates a mental model, uses the related parts of both text and graphics, provides top down and text to picture processing</td>
<td>Model does not provide evidence as of yet</td>
</tr>
</tbody>
</table>
Table 4

<table>
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Integration of instruction plus a causal diagram constructed from the text should lead to a superior mental model, vastly facilitating comprehension and recall.

**Result: Deeper Processing**
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<table>
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<tr>
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<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>Training (N = 31)</th>
<th>Non-Training (N = 31)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>Recall</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total segments</td>
<td>7.19</td>
<td>3.7062</td>
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<tr>
<td>Themes</td>
<td>.10</td>
<td>.301</td>
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<tr>
<td>Intrusions</td>
<td>.03</td>
<td>.180</td>
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<tr>
<td>Drawings</td>
<td></td>
<td></td>
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<tr>
<td>Direct Effect</td>
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<td>.539</td>
</tr>
<tr>
<td>Indirect Effect</td>
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<td>.359</td>
</tr>
<tr>
<td>Predictors</td>
<td>4.71</td>
<td>1.006</td>
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<tr>
<td>Essays</td>
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<td>.643</td>
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<td>Question 3</td>
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<td>.461</td>
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<tr>
<td>Question 4</td>
<td>1.71</td>
<td>.529</td>
</tr>
<tr>
<td>Total</td>
<td>6.32</td>
<td>2.039</td>
</tr>
<tr>
<td>Inferences</td>
<td>.10</td>
<td>.301</td>
</tr>
</tbody>
</table>
REFERENCES


*Educational Psychology Review, 14, (1), 87-100.*

Emerging general consensus, unresolved theoretical issues, and future
Memory: Mechanisms of Active Maintenance and Executive Control,*


(eds.), *Handbook of Visuospatial Thinking,* Cambridge University Press, New
York.

special issue. *Educational Psychology Review, 14, (1), 1-4.*

superior to outlines in improving learning from text. *Journal of Educational
Psychology, 87(3), 455-467.*

increase text recall. *Contemporary Educational Psychology, 18, 401-413.*


*Educational Psychology Review, 14, (1), 27-46.*
VITA

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University of California, Santa Barbara

Thesis Title: Strategic Training in the Use of Causal Diagrams: Facilitation of Superior Mental Models

Thesis Examination Committee:
Chairperson, Dr. Gregg Schraw, Ph.D.
Committee Member, Dr. Ralph Reynolds, Ph.D.
Committee Member, Dr. Gale Sinatra, Ph.D.
Graduate Faculty Representative, Dr. Gretchen Kambe, Ph.D.